VOL. 250 NOVEMBER 1952 No. 11

American Journal of Science

Established in 1818 by Benjamin Silliman

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Published monthly. Eight dollars a year. Seventy-five cents a copy.
Foreign, eight dollars sixty cents. Canada, eight dollars thirty-five cents.

AMERICAN JOURNAL OF SCIENCE

Established in 1818 by Benjamin Silliman

THE FIRST SCIENTIFIC JOURNAL IN THE UNITED STATES

DEVOTED TO THE GEOLOGICAL SCIENCES AND TO RELATED FIELDS

Editor: CHESTER RAY LONGWELL
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Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879. Published monthly at Sterling Tower, Yale University, New Haven, Conn.

Subscription rate $8 per year (75 cents a number). Student rate $5 per year (application blanks available on request). Postage prepaid to the United States and Central and South America; 35 cents per year to Canada; 60 cents per year elsewhere.

The JOURNAL completed its *first* series of 50 volumes in 1845, its *second* series of 50 volumes in 1870, its *third* series of 50 volumes in 1895, its *fourth* series of 50 volumes in 1920, its *fifth* series of 36 volumes in 1938. Since 1938 the numbering by series has been discontinued, and volumes are annual and bear the whole numbers as of 1818, that for 1939 being volume 237.

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[American Journal of Science, Vol. 250, November 1952, Pp. 777-789]

American Journal of Science

NOVEMBER 1952

GRANITIC ROCKS OF THE WESTERN CAROLINA PIEDMONT*

W. R. GRIFFITTS AND W. C. OVERSTREET

ABSTRACT. The rocks in the western Piedmont of North and South Carolina that had been identified as Whiteside granite by earlier workers were discovered by J. B. Mertie, Jr., in 1945 to include two different granitic rocks, neither of which is related to the Whiteside. Work since 1948 has confirmed this. One of these rocks, here named the Toluca quartz monzonite, is best developed near Toluca, North Carolina; the other rock, here called the Cherryville quartz monzonite, is broadly exposed near Cherryville, North Carolina, east of Toluca.

The Cherryville quartz monzonite and related pegmatites were formed after the last strong deformation of the region, and hence are probably of post-Carboniferous age. The Toluca quartz monzonite is older, but its age is unknown.

INTRODUCTION

GRANITIC rocks are shown on the Geologic Map of the United States (Stose, 1932) and the Tectonic Map of the United States (King, 1944) to underlie large areas in the southeastern half of the crystalline rock belt of the southern Appalachians. Similar rocks are widespread in the northwestern part of the crystalline belt, but they occur in comparatively small bodies. Most of these smaller bodies occur in a belt that is shown on the tectonic map as bounded on the northwest by the Brevard overthrust and 65 miles to the southeast by another overthrust. Only a few small bodies of granitic rock occur northwest of the Brevard overthrust.

This paper deals only with the granite of Carboniferous age at Whiteside Mountain in Transylvania County, N. C., and the granitic rocks of various ages in Cleveland, Gaston, and Lincoln

*Publication authorized by the Director, U. S. Geological Survey.

Counties, N. C., and Cherokee County, S. C. The intrusive at Whiteside Mountain is northwest of the Brevard overthrust. The others are between that and the southeastern overthrust.

The more detailed maps of Keith and Sterrett (1931) and Sterrett (1912) show several reverse faults (said to have caused as much as 2,000 feet displacement) along the line that represents the southeastern overthrust. The maps show that the faults occur along, or a few miles east of, the boundary that separates a series of muscovitic schists, quartzites, and marbles on the east from a series of biotitic schists on the west. The rocks on the east side are, in general, less highly metamorphosed than those on the west.

The granitic rocks of the Shelby-Gaffney-Kings Mountain area of the Piedmont of North and South Carolina have been mentioned and described briefly by several geologists in reports on the tin, monazite, or gold resources of the region. Among the later of these are reports by Graton (1906), Sterrett (1908), Keith and Sterrett (1917), and Kesler (1942). The first attempt to show the distribution of granitic rocks in detail was made by D. B. Sterrett and Arthur Keith, who mapped the Gaffney, Kings Mountain, and Lincolnton quadrangles between 1907 and 1912 (Keith and Sterrett, 1931; Sterrett, 1912). They included the granitic rocks of the western parts of these three quadrangles in one unit and assigned this unit to the Whiteside granite which had been defined by Keith (1907) and considered of late Carboniferous (?) age. Two other granites, the Yorkville granite and the Bessemer granite, were mapped in the eastern parts of the same quadrangles but, as they have nothing to do with the subject of this paper, they will not be discussed.

Little more work was done on the granitic rocks of this area until 1945, when J. B. Mertie, Jr., of the U. S. Geological Survey, investigated the monazite deposits of the southeastern Atlantic States. He found two distinctive suites of heavy minerals when he panned weathered rocks obtained from different bodies that have been mapped as Whiteside granite (Mertie, oral communication, 1945). A monazite-bearing suite was obtained from a western belt of rocks, such as those well exposed near Toluca, N. C., and a monazite-free suite was obtained from the rocks in an eastern belt that is well developed near Cherryville, N. C.

Work done by R. G. Yates and W. C. Overstreet since 1948 in the Shelby quadrangle and by W. R. Griffitts since 1949 in the Shelby, Kings Mountain, and Lincolnton quadrangles has provided strong evidence to support Mertie's view that the granitic rocks, mapped as the Whiteside granite in this area by Keith and Sterrett (1931), should be divided into two units. The authors are introducing for these units the new names Toluca quartz monzonite and Cherryville quartz monzonite. The new names were first applied as field designations by J. B. Mertie, Jr., in 1945 (oral communication) and have been used by the authors since that time. As is shown below, the rocks in these new units differ in distribution, texture, mineral composition, content of trace elements, geologic relations, and age.

TOLUCA QUARTZ MONZONITE

The monazite-bearing granitic rock that is exposed near Toluca, N. C., is here named the Toluca quartz monzonite. Weathered rock underlies broad areas of light-gray soil in and near the village, and fresh rock is well exposed in the Acre Rock quarry, which is a few hundred feet north of a dirt road half a mile west of State Highway 18 at a point 0.8 miles southwest of Toluca. The eastern limit of the Toluca quartz monzonite in the recently studied area is shown in figure 1. The western, northern, and southern limits are not accurately known, although the rock probably does not extend more than 35 miles northwest of Shelby.

Most bodies of Toluca quartz monzonite that have been mapped lie parallel to the foliation of the biotitic and sillimanitic schists of the Carolina gneiss. Locally, contacts of the quartz monzonite cross the foliation, and a few bodies are dikes that clearly cross the planar structures of the host rocks. Individual bodies range from a few inches to several thousand feet in thickness and from a few feet to at least 10 miles in length. Most are lenticular but some are irregular. As they are parallel to the planar structures of the gneiss, which have been folded, the outcrop patterns are very complex in some places.

The Toluca quartz monzonite is typically a medium-gray moderately to strongly gneissic rock. Commonly the smaller sills are more strongly foliated than the larger, which, though

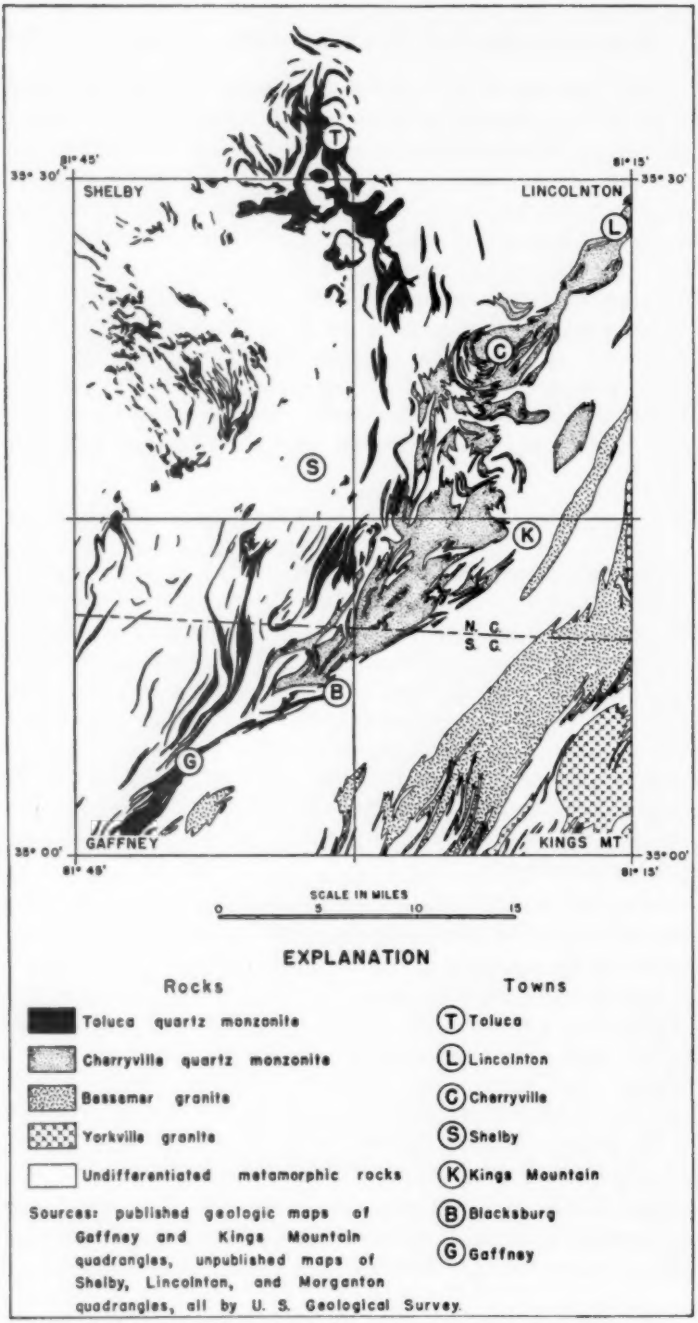

Fig. 1. Granitic rocks of the western Carolina Piedmont.

recognizably gneissic throughout, are most strongly foliated near the margins. The best-developed gneissic structure consists of layers that are rich in quartz or biotite separated by layers that are composed largely of feldspars, with only subordinate amounts of quartz and biotite. In the interior of the larger sills, where the segregation of minerals is not pronounced, the foliation is shown by a fair parallelism of mica flakes and small leaves of quartz. Linear structures are commonly well developed on the foliation planes. They include elongate, flat leaves of quartz and elongate clusters of biotite flakes set in quartz or feldspar. The quartz leaves exceptionally reach a maximum length of several inches; most are less than an inch long. Their width is usually about one-fifth of their length, and their thickness is only a small fraction of their width. In the Acre Rock quarry the foliation is folded and cut by faults, which apparently have caused only small displacement. Pegmatite and aplite have been introduced along some of these faults, as well as along other fractures on which there has been no apparent movement. All these fractures seem to have little directional relation to the foliation or lineation of the quartz monzonite.

The foliation of the Toluca quartz monzonite, where not folded, is parallel to the contacts of the rock mass; thus, in the conformable bodies, it is parallel to the foliation of the enclosing schists as well. The lineation of the quartz monzonite is parallel to the length of elongate aggregates of quartz and biotite grains in the schists, and inclined to or normal to other linear structures of the schists.

The major mineral constituents of the Toluca quartz monzonite are: oligoclase, microcline, orthoclase, quartz, and biotite. Muscovite, a minor constituent, commonly is intergrown with microcline, oligoclase, and quartz. Garnet is in nearly spherical grains, most of which have a diameter of about one-tenth inch. Biotite generally occurs in tiny flakes, less than one-fortieth inch in diameter; these flakes, where scattered through the lighter colored feldspar and quartz, give the rock a finely spotted appearance. The feldspar grains are commonly one-twentieth to one-fourth inch across. Quartz, as mentioned above, occurs both segregated in leaves and disseminated in feldspar-quartz layers. Because the quartz is commonly segregated into layers and leaves, the degree of foliation of the rock varies with its quartz content. Myrmekitic intergrowths of quartz and oligoclase

are common. Apatite, zircon, and monazite can be found in thin sections of the rock. As accessory minerals, ilmenite, zircon, and monazite can be recovered from weathered Toluca quartz monzonite nearly everywhere, by panning. Garnet, rutile, and sillimanite are widespread but are not nearly as universally present as the minerals mentioned above. Dark-blue spinel and green xenotime have been noted in a few samples.

One of the characteristics of the Toluca quartz monzonite is its wide variation in both texture and composition. The texture is nearly everywhere gneissic, but the size, shape, and arrangement of grains vary widely. Injection of varying amounts of the quartz monzonite and recrystallization of the country rocks further complicate the mapping of the rock masses, although wherever exposures are found the contact between the Toluca quartz monzonite and Carolina gneiss is sharp.

Spectroscopic analysis of Toluca quartz monzonite and the related pegmatite shows that both contain zirconium, strontium, and lead, as well as the commoner elements. Monazite and xenotime in the rocks indicate the presence of small amounts of phosphorus, thorium, and rare earths, although those elements were not detected spectroscopically.

Monazite-bearing pegmatite is associated with the Toluca quartz monzonite in many places. It occurs both in the Toluca quartz monzonite and in the Carolina gneiss, in irregular or tabular masses and in nodules or knots a few inches to several feet thick that lie parallel to the foliation, as well as in dikes and sills that reach lengths of several hundred feet. Much of the pegmatite resembles a coarse-grained augen gneiss, with layers of fine-grained quartz and oligoclase wrapped around oblong "eyes" of microcline. The microcline grains have been deformed, as shown by fracturing and bending of the cleavage surfaces. Nonperthitic microcline, oligoclase, and quartz are the major constituents. In most places the microcline constitutes about one-third of the rock, plagioclase a little more than one-third, and quartz a little less than one-third. In two rather uncommon varieties, however, the microcline content is as much as 60 to 80 per cent and as little as 5 to 10 per cent. The oligoclase content varies inversely as the microcline content, and the quartz content remains in the range of 20 to 35 per cent. Biotite rarely constitutes more than 10 per cent of the pegmatite,

and in many places it is absent. Garnet is more uniformly distributed, but rarely occurs in amounts greater than 5 per cent. Small amounts of monazite, sillimanite, xenotime, zircon, ilmenite, tourmaline, and rutile can be recovered by panning.

A close genetic relationship between the pegmatite and the Toluca quartz monzonite is indicated by: the close spatial relations between them, the fact that both have been deformed to about the same extent and in the same manner, the fact that the structural behavior of the country rock seems to have been the same during the emplacement of both rocks, and the presence of monazite and xenotime in both rocks. These minerals are not characteristic of other rocks in the area. It is interesting to note that both the quartz monzonite and the pegmatite contain the same trace elements, although the major constituents may be different.

CHERRYVILLE QUARTZ MONZONITE

The monazite-free rock exposed near Cherryville, N. C., is here named the Cherryville quartz monzonite. It underlies a broad belt that is widest between Cherryville and Kings Mountain, N. C., but it forms few large outcrops of hard rock in that area. The best exposures found so far are in and alongside Muddy Creek at a bridge 4 miles southeast of Elizabeth Church and 6 miles east of Shelby, N. C., and in a small quarry about half a mile east of Long Creek Church and 4 miles northeast of Kings Mountain. The last-mentioned exposure is in a small satellitic body rather than in the main batholith, but it is of typical Cherryville quartz monzonite.

The Cherryville quartz monzonite belt lies parallel to the layering of the enclosing rocks between Blacksburg, S. C., and Cherryville, N. C. To the north, however, it bends eastward, crossing the structure of the older rock. The quartz monzonite contains many concordant inclusions and septa of country rock, the contacts of which are generally parallel to their foliation, and only locally cross-cutting. These inclusions may reach a length of several miles. The quartz monzonite of the belt may conveniently be considered as a batholith containing much included country rock.

Three distinct and uniform varieties of Cherryville quartz monzonite have been recognized. The commonest variety is a

gray even-grained massive to faintly gneissic muscovite-biotite rock. Phenocrysts of potash feldspar occur in this type rock in a small area near Lincolnton but the contrast in grain size between them and the groundmass is not great. A second variety of the Cherryville quartz monzonite, moderately widespread through the batholith, contains muscovite but not biotite; this muscovite-quartz monzonite is a minor component of the batholith, probably not amounting to more than 10 or 15 per cent of it. A third variety, perhaps as abundant as the muscovite-quartz monzonite, seems to occur mainly at the south end of the batholith, near Blacksburg, S. C., and in scattered small bodies near the western margin of the batholith. It is very strongly lineated rock, with streaks and spindles of quartz and biotite. Planar structures are commonly poorly developed. None of the three varieties of quartz monzonite varies greatly in character.

Dikes of the light-colored muscovite-quartz monzonite in the darker muscovite-biotite rock, and intrusive breccias with fragments of the dark-colored rock imbedded in the light-colored, indicate a difference in age between the two varieties. The lineated rock may differ somewhat in age from the other varieties, but its relations are not well known.

The major constituents of the Cherryville quartz monzonite are oligoclase, microcline, quartz, biotite, and muscovite. The feldspar grains are commonly one-sixteenth to one-fourth inch across, and the mica flakes are one-thirty-second to one-sixteenth inch in diameter. Zircon, ilmenite, and apatite are the accessory minerals, but are uncommon. The nonlineated varieties of Cherryville quartz monzonite characteristically yield only a very small heavy mineral concentrate upon panning; zircon and ilmenite are the only two heavy minerals that are ordinarily found.

Spectroscopic analysis of the Cherryville quartz monzonite and related pegmatites has shown the presence of gallium, phosphorus, copper, and the commoner elements. The contrast between the suites of trace elements in the Cherryville and Toluca quartz monzonites is shown in table 1.

Several varieties of pegmatite are related to the Cherryville quartz monzonite. Spodumene-bearing pegmatites are restricted to a belt known as the tin-spodumene belt (Kesler, 1942) that is close to the eastern margin of the batholith, most commonly

in the schist or gneiss, but in a few places in the Cherryville quartz monzonite. These pegmatites are composed largely of nonperthitic microcline, albite, quartz, muscovite, and spodumene, with beryl, tourmaline, and cassiterite as common accessory minerals. Most of the pegmatite bodies north of Kings Mountain are well zoned but not gneissic, whereas many of those to the south are gneissic but not especially well zoned. Other pegmatite dikes occur farther west, within the batholith; they contain perthite, oligoclase, quartz, and muscovite. These dikes range in width from a few feet to about 20 feet; most are tabular and sharply bounded bodies, but irregular masses of pegmatite and isolated perthite crystals imbedded in the quartz monzonite accompany the dikes in places. Some dikes in the quartz monzonite are well zoned, others are not.

Mica-bearing pegmatites in the northwestern part of the Lincolnton quadrangle and in the Shelby quadrangle apparently are related to the Cherryville quartz monzonite. They form dikes and lenses that cross the foliation of the enclosing schists and of the Toluca quartz monzonite. They are well zoned and contain no monazite and little ilmenite, even though the enclosing rock may contain those minerals in moderately large amounts. The content of heavy minerals other than apatite is exceedingly low. The major constituents are perthite, oligoclase, quartz, and muscovite. Biotite is not uncommon but rarely is abundant.

All of these pegmatites are thought to be related to the Cherryville quartz monzonite. The evidence for this varies, naturally, depending upon the type and occurrence of the pegmatite. It is obvious that the spodumene-bearing and mica-bearing pegmatites that cut the Cherryville quartz monzonite cannot be older than it. In a few places the quartz monzonite was readily recrystallized during pegmatite emplacement, which suggests that it may have been at a temperature not far below that of its consolidation and therefore probably was then quite young. The similar pegmatite dikes in the schist and gneiss bordering the batholith are probably of the same age as the dikes within the batholith.

The behavior, during panning, of kaolinized Cherryville quartz monzonite from the type area differs from that of kaolinized Toluca quartz monzonite. Mr. Mertie has told the authors that the clay of the weathered Cherryville quartz monzonite

is dispersed in water with more difficulty than that of other weathered granites he has examined (oral communication, 1951). The quartz residue is small, which might be attributed either to an unusually low quartz content of the rock or to the friability of the quartz, which causes it to break up and drift away with the clay during washing. The gummy texture of the clay may result from some peculiarity in the composition of the feldspar.

GEOLOGIC RELATIONS AND RELATIVE AGES

Inasmuch as the bodies of Toluca quartz monzonite are parallel to the foliation of the Carolina gneiss they partake of the folding of the gneiss. The folds whose attitudes are known plunge gently, most commonly southward, less commonly northward. The body of Cherryville quartz monzonite, on the other hand, may plunge steeply to the west or southwest.

There is, unfortunately, no direct method of dating the quartz monzonites. The indirect evidence itemized below strongly indicates that the Toluca quartz monzonite is the older.

1. Folds are the structures characteristically associated with bodies of Toluca quartz monzonite, whereas fractures are characteristically associated with the Cherryville quartz monzonite bodies. This indicates that the Toluca quartz monzonite was emplaced under conditions of flowage, and the Cherryville quartz monzonite was emplaced under conditions of fracture. As both rocks are in the same area, this difference in environment strongly suggests a difference in age.

2. The faults that controlled the emplacement of pegmatites related to the Cherryville quartz monzonite offset typical Toluca quartz monzonite and related pegmatite, and pegmatite dikes related to the Cherryville quartz monzonite cut Toluca quartz monzonite. It is recognized, however, that the pegmatites might differ slightly in age even if the quartz monzonites were essentially contemporaneous.

3. The Toluca quartz monzonite and related pegmatite have been deformed and the Cherryville quartz monzonite and most of its related pegmatites have not.

Indirect evidence suggests that the Cherryville quartz monzonite is of very late Paleozoic age. Coarse muscovite books, being easily cleaved along the rays of the pressure figure and

easily bent or buckled, are very sensitive indicators of post-crystallization deformation. The mica in the pegmatites related to the Cherryville quartz monzonite has not been deformed. Hence, it must have been emplaced since the last intense orogeny of the area. The pegmatites are cut by diabase dikes that are considered to be of Triassic age. The mica-bearing pegmatites, therefore, were probably emplaced after most of the movements of the Appalachian revolution had taken place, but before the intrusion of the Triassic diabase dikes. A close relationship exists between the Appalachian structures and the distribution of pegmatites, which indicates that the pegmatite formation was closely related to that revolution. The Cherryville quartz monzonite, like some of the other granitic rocks that are related to the mica-bearing pegmatites, presumably also is of late Paleozoic age. The Toluca quartz monzonite is older than the Cherryville quartz monzonite and its age is therefore considered to be Carboniferous (?) or pre-Carboniferous (?).

The Toluca quartz monzonite and Cherryville quartz monzonite are sufficiently different to be distinguished in the field, and differ enough in age and origin to be considered distinct units and assigned different names. Keith and Sterrett (1931) included both rocks in one unit only because of a general similarity between them, and assigned them to the Whiteside granite. The Whiteside granite at its type locality is in part a medium-grained biotite-muscovite-quartz monzonite, having a composition that is common in granitic rocks through much of the Southeast. It also includes a coarse-grained pegmatitic rock dissimilar to the Toluca and Cherryville quartz monzonites. It contains few accessory minerals—as does the Cherryville quartz monzonite—but the mode of occurrence more closely resembles the Toluca quartz monzonite. The term "Whiteside granite" should not be used in this area, but should be restricted to the granite at and near Whiteside Mountain, the type locality.

The main features of the Toluca and Cherryville quartz monzonites are shown in table 1. The two rocks are obviously different even though their chemical compositions are known to be quite similar. For comparative purposes the available data on Whiteside granite (from its type locality) are included. In view of the general close resemblance between granitic rocks of the Southeast, the differences between these three rocks are sufficiently well marked to permit a distinction.

TABLE 1

Characteristics of the Toluca and Cherryville quartz monzonites and the Whiteside granite

	Toluca quartz monzonite	Cherryville quartz monzonite	Whiteside granite
Distribution ...	Western part of area of figure 1	Eastern part of area of figure 1	West of area of figure 1, in Blue Ridge
Broadest relation to country rock	Parallel	Crosscutting	Parallel
Texture	Gneissic	Massive	Massive
Mineral composition:			
Major minerals	Muscovite, biotite, oligoclase, microcline, quartz, garnet	Muscovite, biotite, oligoclase, microcline, quartz	Muscovite, biotite, oligoclase, microcline, quartz
Minor minerals..	Ilmenite, monazite, zircon, apatite	Ilmenite, zircon, apatite	Ilmenite, pyrite, zircon, garnet, local monazite (?)
Content of heavy minerals	Moderate	Very low	Very low
Chemical composition:			
Major elements	Normal quartz monzonite	Normal quartz monzonite	Normal quartz monzonite (?)
Characteristic minor elements	Sr, Zr, Pb, Th, rare earths	Ga, P, Cu, Sn, B	
Amount of injection of country rock	Moderate to large	Little	Moderate
Time of emplacement:			
Relation to deformation	Contemporaneous	After	After
Relation to other intrusives in vicinity* ..	Next to last	Last	Next to last?
Age	Carboniferous (?) or pre-Carboniferous (?)	Post-Carboniferous (?)	Late Carboniferous (?)

* Excluding diabase dikes of probable Triassic age.

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[American Journal of Science, Vol. 250, November 1952, Pp. 790-801]

SIZE DISTRIBUTION IN THE SAND FRACTIONS OF SOILS

DOROTHY CARROLL

ABSTRACT. Mechanical analyses of two series of soils associated with fossil laterite formed (A) on granitic and gneissic rocks, and (B) on fine grained sandstones are given as examples of the sorting which is found in such materials. The size distributions obtained are shown as cumulative percentage (weight) curves. The figures were analyzed statistically by Krumbein and Pettijohn's "short method" (1938). This method of treating the data is shown to have possibilities for use in the examination of soils and residual material, for soils derived *in situ* from granitic rocks tend to exhibit a positive skewness in their size distribution, whereas soils from sedimentary rocks have a negative skewness.

INTRODUCTION

THE size distribution of fragments of source rocks of sediments was discussed by Krumbein and Tisdel (1940) and later by Pettijohn (1949). It appears that the size distribution shows some similarity to that of artificially crushed materials. As soils are the natural products of weathering, particularly those *in situ* above rock which is known to be the parent rock, it seems likely that useful information on grading may be obtained from examining the mechanical composition of the sand grades of soils; and further, the interpretation of any information obtained may assist in describing such soils and in elucidating their genesis.

When a non-sedimentary rock weathers and a soil is formed, the completeness of the change from fresh rock to soil will depend on several factors, principal among which may well be the chemical composition, for this determines the amount of change or movement of constituents that can take place under varying climatic conditions. For example, it is well known that among igneous rocks basalt is much more weatherable than granite because the silica in the latter causes the presence of free quartz which will disintegrate under soil forming conditions, but which will remain more or less *in situ* if the soil is sedentary and is developing on a flat land surface. The greater the length of undisturbed time the soil has for development, the greater will be the disintegration of the original grains into smaller ones. This will influence the size distribution obtained, but it is not at present known what conditions will influence the end-point or what the final sizes of grains will be.

A sedimentary rock, such as a sandstone, has a size distribution of its constituents which has been imposed on it by the processes of transportation and deposition; when such a rock forms soil the weathered material exhibits a size distribution which may be similar to that of the parent rock. This is particularly reflected in a soil derived *in situ* from a sandstone.

In the mechanical analysis of soils, however, and particularly in the International Method (Piper, 1947, p. 53) which has been widely adopted by agricultural institutions, the true size distribution of grains is largely disguised by the choice of class sizes. In the International System the grades are:

Stones	— 0.2 mm.
Coarse sand 2	— 0.02 mm.
Fine sand 0.2	— 0.002 mm.
Silt	+ 2 mm.
Clay	< 0.002 mm.

A soil mechanical analysis emphasizes the importance of the clay and silt grades. By using the Wentworth grade scale for the sand fractions of soils any inherent sorting of grains is readily seen, and furthermore the data can be analyzed statistically.

This paper presents and discusses two sets of data on the grading of sand grains in soils. *Series A* contains soils which were originally derived from hard rocks. These soils have all, except one, suffered laterization, which implies severe leaching under tropical conditions. They are old soils which have been preserved as erosion remnants. *Series B* contains four soil profiles which have developed on very fine grained Miocene sandstones. These also have been influenced by laterization to some extent, so that they are comparable to the soils in Series A.

DESCRIPTION AND MECHANICAL COMPOSITION OF THE SOILS

Series A. — The soils in this series were collected from inland Western Australia at the localities shown in table 1. They are very old soils which were formed on a peneplaned surface now standing about 1,200 feet above sea-level. This plateau has been only slightly affected by erosion, and in large areas the soils have not been disturbed since their formation which is considered to have been during the Pliocene when the climate was much

warmer and moister than it is at present, resulting, as recognized by Prescott (1931), in the development of laterite soil profiles. As there are extensive areas underlain by granitic and gneissic rocks, the type of laterite formed has a sandy surface, or A horizon, in contrast to the bauxitic type which is more characteristic of basic rocks in Australia (Carroll, 1939, 1951). Where undisturbed the A horizon of the laterite soil forms extensive sand-plains (mainly in the dry areas); where erosion has occurred at the edges of the plains mixed soils have developed from the clayey materials below the hard nodular laterite layer. A full description of these is given by Stephens (1946).

TABLE 1

Size Distribution for Series A Soils (Weight Percentage)

Grade mm.	ø	1	2	3	4	5	6	7	8
		Per cent							
8 — 4	—3— —2	0.4	1.9	1.6	—	—	—	—	—
4 — 2	—2— —1	2.3	3.8	3.7	0.1	1.0	—	—	—
2 — 1	—1 — 0	12.9	3.7	1.2	2.7	11.5	3.0	12.1	2.9
1 — ½	0 — 1	15.4	6.9	22.9	20.9	27.5	28.8	18.4	15.7
½ — ¼	1 — 2	24.8	26.7	21.2	35.9	18.5	30.1	21.4	22.2
¼ — ⅛	2 — 3	25.6	34.2	25.3	25.9	25.5	18.3	22.8	35.2
⅛ — $\frac{1}{16}$	3 — 4	11.4	14.8	18.4	10.0	12.0	9.7	14.8	14.8
$\frac{1}{16}$ — $\frac{1}{32}$	4 — 5	8.9	7.8	5.7	4.3	4.0	10.1	10.5	9.2

1. Red soil, Parker's Range road, Yilgarn Goldfield.
2. Yellow sand-plain soil, between Cockatoo Tank and Parker's Range, Yilgarn Goldfield.
3. Yellow sand-plain soil, between Marvel Loch and Strawberry Rocks, Yilgarn Goldfield.
4. Yellow sand-plain soil, between Marvel Loch and Cockatoo Tank, Yilgarn Goldfield. (For 1-4, see Carroll, 1939.)
5. Yellow sand-plain soil, Tammin.
6. Surface sandy soil, laterite over granite, Wongan Hills.
7. Surface to 24 inches, laterite over gneiss, Greenbushes.
8. Surface to 3 inches, laterite over gneiss, Rocky Gully. (For 6-8, see Carroll and Jones, 1947.)

Table 1 and figure 1 give the results obtained from sieving eight sandy soils from the surface of lateritic profiles. The soils were air dried and sieved with Tyler sieves giving the Wentworth grades. Nos. 1-4 were hand sieved, the remainder being sieved on a Ro-tap for fifteen minutes each. The figures in table 1, particularly for nos. 2, 3, and 4, and for 6, 7, and

8 are interesting in that they give what is probably the final result of long-continued weathering of a strenuous nature. The grains are practically all quartz, the other constituents having been removed. It is probable, too, that some alteration of the original angular shape of the quartz has taken place, for microscopic examination shows that the majority of the grains are sub-angular to sub-rounded and not truly angular such as are found in a soil recently derived from a granitic rock. Even the largest grains are individual minerals. The mechanical com-

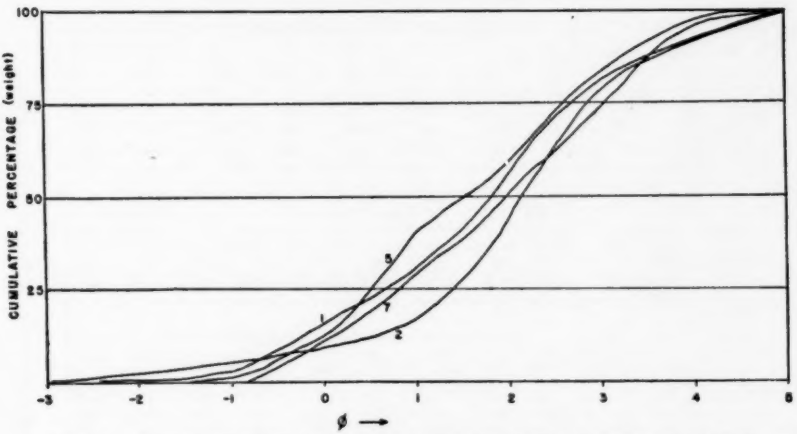

Fig. 1. Cumulative curves for Series A surface soils. Localities as in table 1. Nos. 1, 2, 5, and 7.

position is in agreement with that for nos. 6 and 7, table 1, Krumbein and Tisdel (1940, p. 298) except for the smaller amount of material in the minus one-sixteenth mm. grades.

Series B.—The soils in this series were collected in 1946 by L. J. H. Teakle during the course of a detailed soil survey of an area of over 29,000 acres in the Mt. Many Peaks district (Lat. 35°S., Long. 118°E.) on the south coast of Western Australia. Mechanical analyses were made of over fifty samples from which the figures given here were selected by the writer as being representative of the soil profiles in the area. The Mt. Many Peaks area consists of a basement of early Precambrian gneisses and granites overlying which are marine sediments of Miocene age, the Plantagenet Beds. These sediments form a

gently undulating plateau at about 300 feet above sea-level; high gneissic hills occur at various places, notably Mt. Many Peaks (1,885 ft.). The Plantagenet Beds were deposited in

TABLE 2

Size Distribution for Series B, Soils (Weight Percentage)

Name:		Carinyah loamy sand			Waychinicup loamy sand			
Sample No.		1	2	3	1	2	3	4
Depth in inches		0-4	10-18	40-56	0-3	3-7	7-20	39-60
Grade mm.	φ	Per cent						
2 — 1	— 1 — 0	1	3	2	2	8	5	6
1 — ½	0 — 1	3	4	4	2	16	9	2
½ — ¼	1 — 2	3	3	3	6	8	5	1
¼ — ⅛	2 — 3	8	8	6	10	9	8	4
⅛ — 1/16	3 — 4	51	41	43	51	35	32	31
1/16 — 1/32	4 — 5	32	41	42	29	23	40	54

Name:		King Creek sandy loam						Corimup sand		
Sample No.		1	2	3	4	5	6	1	2	3
Depth in inches		0-4	4-9	9-18	18-36	54-63	90-120+	0-7	16-48	48-72
Grade mm.	φ	Per cent								
2 — 1	— 1 — 0	10	1	18	5	—	—	1	—	—
1 — ½	0 — 1	9	8	24	15	13	1	12	9	3
½ — ¼	1 — 2	8	8	6	8	8	1	16	15	9
¼ — ⅛	2 — 3	12	20	9	12	12	2	30	34	39
⅛ — 1/16	3 — 4	35	40	22	20	27	39	35	36	42
1/16 — 1/32	4 — 5	25	21	18	40	38	56	5	5	6

fairly deep water and are very fine grained and siliceous; in places individual beds consist almost entirely of siliceous sponge spicules, and other fossils have also been replaced with silica. After uplift, coastal sand dunes, which later consolidated into the Coastal Limestone (Pleistocene) covered parts of the Miocene. Subsequently the surface of the plateau was laterized, and the sand dunes and Coastal Limestone largely removed, but some fossiliferous limestones still remain. The lateritic surface is now in the process of slow removal, and in places the surface of the ground is strewn with ironstone gravel (loose pisolitic laterite); ironstone boulders also occur. The area is, therefore, somewhat similar to that described for Series A soils, except that the soils in the Many Peaks area have been formed from sedimentary material.

The soils, described and named by Teakle (1951), appear to be the result of pedogenic factors acting on an undulating plain of an original laterite which is now in all stages of truncation. An important characteristic of all but one of the soils "is the fineness and apparent even grading of the sand."

In order to show the relationship between the sand fractions of the soils in the various profiles the organic matter and clay were removed by the standard methods for soil analysis (Piper, 1947, p. 53). The air-dry sand was shaken through a set of Tyler sieves on a Ro-tap for fifteen minutes. The material

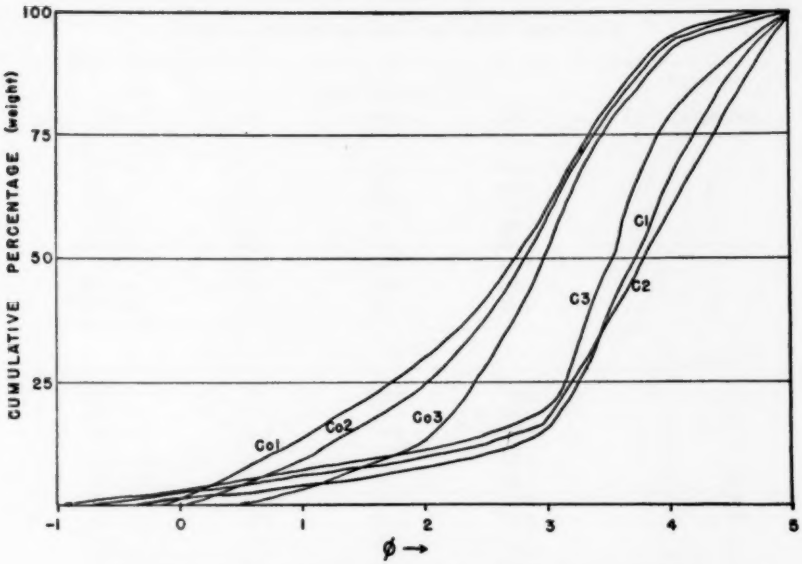

Fig. 2. Cumulative curves for Series B soil profile samples.
C = Carinyah loamy sand (C1, 0-4; C2, 10-18; C3, 40-56 inches).
Co = Corimup sand (Co 1, 0-7; Co 2, 16-48; Co 3, 48-72 inches).

passing the 250 mesh (0.06 mm. diameter) sieve was all plus 0.02 mm., but is reported in table 2 as plus 0.03 mm. The material in each grade was examined microscopically and visual estimations of the degree of roundness made according to Krumbein's chart (1941). Cumulative percentage (weight) curves are given in figures 2, 3, and 4. The parentage of the soils was checked mineralogically with that of the underlying rocks wherever possible.

DISCUSSION

The size distribution figures in tables 1 and 2 were analyzed statistically by Krumbein and Pettijohn's "short method" (1938, p. 251) to give the phi mean (Mø), the phi standard deviation ($\sigma\phi$), and the skewness ($a_{3\phi}$) which appear in table 3. There are a number of points to be observed from the data.

Series A.—Firstly it is apparent, on comparison with Krumbein and Tisdel's (1940) findings for source rocks, that posi-

TABLE 3

Statistical Data for Soils in Series A and B

Sample	Mφ	Geometric mean mm.	σφ	$a_3\phi$
Series A				
1	1.52	0.37	1.56	+0.71
2	2.24	0.22	1.41	—0.59
3	1.86	0.29	1.49	—0.24
4	1.82	0.28	1.12	+0.20
5	1.58	0.35	1.38	+0.075
6	1.83	0.30	1.32	—0.49
7	1.92	0.27	1.51	+0.056
8	2.21	0.22	1.24	+0.006
Series B				
Ca 1	3.55	0.09	0.97	—1.43
Ca 2	3.53	0.08	1.21	—0.91
Ca 3	3.60	0.09	1.08	—1.96
W 1	3.42	0.10	1.06	—1.54
W 2	2.68	0.17	1.63	—0.81
W 3	3.26	0.10	1.56	—0.44
W 4	3.70	0.09	1.32	—1.09
KC 1	2.80	0.21	1.61	—0.43
KC 2	3.07	0.12	1.19	—0.28
KC 3	1.94	0.53	1.83	—0.044
KC 4	2.97	0.14	1.84	—0.30
KC 5	3.23	0.10	1.39	—0.34
KC 6	4.00	0.06	0.68	—1.01
Co 1	2.53	0.20	1.51	+0.023
Co 2	2.64	0.17	1.05	—0.56
Co 3	2.90	0.15	0.86	+0.24

Ca = Carinyah loamy sand profile, depths of samples as in table 2.
W = Waychinicup loamy sand profile, depths of samples as in table 2.
KC = King Creek sandy loam profile, depths of samples as in table 2.
Co = Corimup sand profile, depths of samples as in table 2.

All samples in Series A are from the surface. Localities as in table 1.
Mφ = phi mean; σφ = phi standard deviation; $a_3\phi$ = skewness.

tive skewness does occur in these residual materials from granitic rocks, for five out of eight soils collected above disintegrating granite and/or gneiss show positive skewness even although all of these, except no. 1 (table 1), have been subjected to laterizing processes whereby the silica originally combined in such minerals as feldspars has been removed. (For the purposes of this study it is presumed that the quartz of the original rock has merely been reduced to natural sizes and that none of it has been removed by solution, an assumption which, while doubtful, has not yet been satisfactorily demonstrated.)

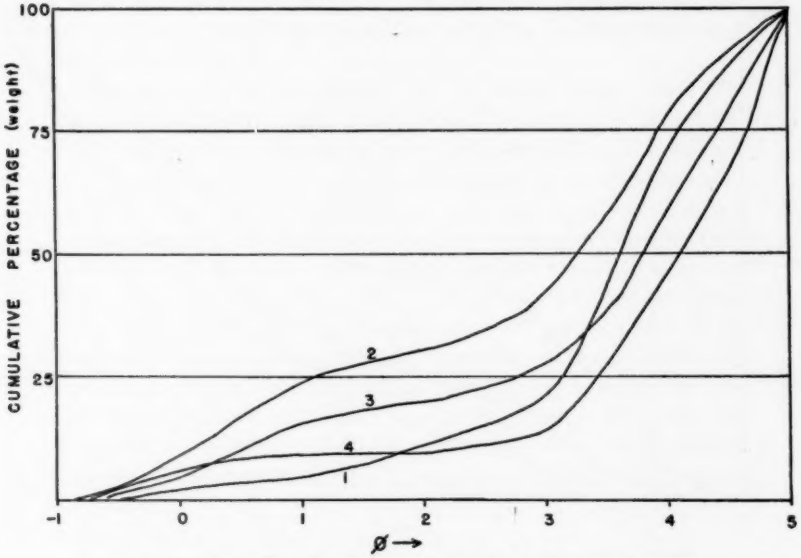

Fig. 3. Cumulative curves for Series B soil profile samples. Waychinicup loamy sand (1, 0-3; 2, 3-7; 3, 7-20; 4, 39-60 inches).

In this series both Mø and geometric mean diameter are similar to those obtained by Krumbein and Tisdel (1940, p. 299) for chemically weathered materials. Except for no. 1, the skewness is not very strong. The phi standard deviations range between 1.24 and 1.56, so that the main grouping of the material is over two and one-half to three Wentworth grades. The geometric mean varies between 0.22 and 0.37 mm.

Series B.—Table 2 gives the size distribution of sand grains for four soil profiles which were carefully examined in the field and mapped as units in a soil classification by Teakle (1951).

These soils were mechanically analyzed according to the International Method (Piper, 1947, p. 53), but this tended to obscure differences and similarities in the grading of the samples. Knowing that the soils were derived from a fine-grained sandstone and were sedentary, it was decided to examine the size distribution of the original sedimentary material from which they were derived; in other words, to simplify the situation by treating the sand grades as sediments, and ignoring the complicating factors of clay fraction, lateritic pebbles, and organic matter. Table 3 gives the statistical analysis of these materials.

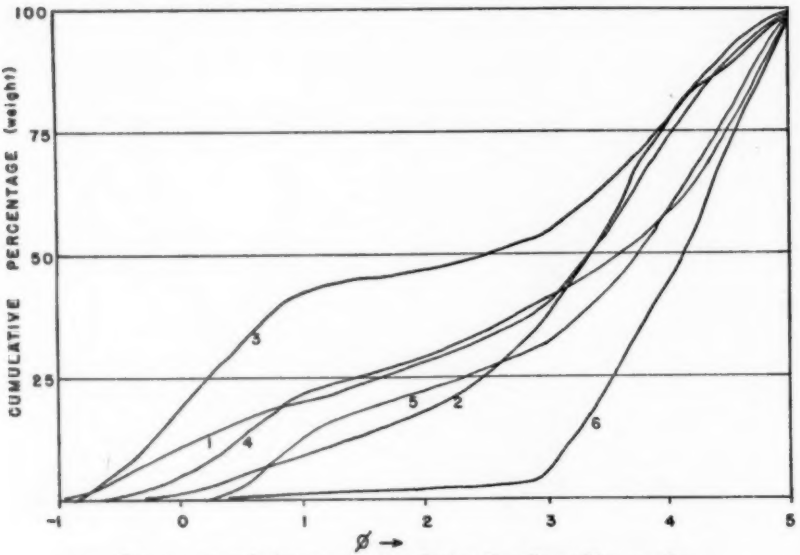

Fig. 4. Cumulative curves for Series B soil profile samples. King Creek sandy loam (1, 0-4; 2, 4-9; 3, 9-18; 4, 18-36; 5, 54-63; 6, 90-120+ inches).

If samples KC 1-6 (King Creek sandy loam) (fig. 4) be examined first a number of points are noticeable. There is a marked variation in Mø and thus in the geometric mean diameter. KC 6 has Mø = 4.0 which can be taken as that for the parent rock, for the sample actually consisted of disintegrating fine-grained sandstone. The grain size becomes much larger towards the top of the profile, with a maximum of 0.53 mm. in KC 3 (9-18 inches). Had the sandy material from KC 6 alone acted as soil material it would not be possible for this to occur.

and it must be assumed that some other material has contributed to the upper parts of the profile. The King Creek sandy loam profiles generally show, according to Teakle (1951), a gravelly layer (lateritic gravel) at a depth of 18 to 20 inches, and it is this layer which has changed the grading in KC 3. Microscopic examination reveals that fragments of brown material (lateritic ironstone) occur in the sand of this horizon, together with larger quartz grains. The phi standard deviation of these sands varies from 0.68 at the base to 1.61 at the surface, with the poorest sorting in KC 3 and KC 4, influenced by laterization. The sandstone at the base has a skewness of —1.01, but this becomes less, though still negative up to the surface. The least skewness is in KC 3.

Looking next at the profiles of Carinyah loamy sand (Ca 1-3) and the Waychinicup loamy sand (W 1-4) (figs. 2 and 3), it will be found that Mø shows very little variation and it follows that the geometric mean grain size is also very similar throughout. The base of each profile has a strong negative skewness (—1.96 and —1.09, respectively) which is comparable with that of KC 6 and indicates that similar parent material occurred below these three profiles. The sorting, shown by σø, is somewhat similar and shows approximately the same order as in parts of the King Creek sandy loam profile. It is apparent that there has been no addition of material from outside sources, and that these two soils have been derived, with little change, from the underlying sandstone. However, it is worth noting that the skewness is strongly negative in both the surface samples (Ca 1 and W 1) in contrast to the surface of the other profile (KC 1).

Turning now to the Corimup sand (Co 1-3) (fig. 2) it can be seen that Mø is lower than in the other three profiles with the exception of samples W 2, KC 1, and KC 4. The geometric mean grain size of the basal sample (Co 3) is larger than in the other profiles, but is not appreciably different from the upper part of the Waychinicup (W 1-3). Co 1 is approximately the same as KC 1, and Co 2 is similar to KC 2 and KC 4. The phi standard deviation at the base (Co 3) shows that the sorting here is better than nearer the surface of this profile, but the greatest difference exists in the positive skewness of Co 1 and Co 3. It is probable, knowing the field occurrence, that the variation in the King Creek sandy loam profile is due

to the admixture of material of Corimup sand type. At the base (Co 3), and throughout this profile, careful examination shows small fragments of sandstone, and although this particular sandstone has not been recognized as the parent material of any soil type in the area, it is probable that a bed with coarser grain size does overlie the fine-grained sandstone which has given rise to the Carinyah and Waychinicup soil types. The Plantagenet Beds contain a number of distinct sandstones which have not yet been mapped in detail. Laterization processes have acted on both coarse- and fine-grained sandstones, but do not appear to have had any influence on the thin soils developing on the Precambrian rocks.

If now the surface samples of Series B (Ca 1, W 1, KC 1, and Co 1) are compared with the samples in Series A (all surface) many differences will be noted. Mø for Series A has six samples between 1 and 2, and two between 2 and 3. The geometric mean diameters in Series A are all larger than in B, though Co 1 is similar to no. 8 in A and KC 1 is similar to no. 2 in A. The phi standard deviations for Series B are not uniform being Ca 1, 0.97; W 1, 1.06; KC 1, 1.61; and Co 1, 1.51. Of these, Co 1 falls into the range for Series A, which, as noted above, is fairly uniform. This indicates that only two of the surface soils derived from sandstones show better sorting than the surface soils of granitic materials. This fact may be of value in describing soils thought to be of sedimentary parentage. The fact, too, that $\sigma\phi$ for any sample of the Waychinicup loamy sand profile, except the surface, and for samples of the King Creek sandy loam down to below 63 inches could equally well belong to soils derived from hard rocks is interesting and serves to show the necessity of examining soils down to the parent material so that a correct interpretation be obtained. It is, however, in the skewness that the greatest differences are found, only one (Co 1) of Series B being positively skewed. Three soils of Series A are negatively skewed; such a negative skewing may show slight movement of hard rock disintegrating materials.

CONCLUSIONS

The statistical treatment of the size distribution of these two series of soils with different parent material, but developed under similar climatic and topographic conditions, indicates that this method has possibilities when applied to the description of soils. In addition the examination of samples from individual

soil profiles provides a means of suggesting origin, and the soils of the Mt. Many Peaks area provide good examples for this purpose. The listing of percentages by weight for the various Wentworth grades in mechanical analyses cannot be so readily used in interpretations of this kind. The examination by this method of soils of unknown parentage should be done with caution, but considerable information about size distribution in disintegrating material of all kinds could be made available with very little extra work in most soils laboratories. The data for Series A soils, which were collected from several widely separated areas, indicate that there is some general size distribution for disintegrating granitic type rocks, and that the skewness will more often be positive than negative.

ACKNOWLEDGMENTS

The mechanical analyses of most of the soils described here were made by the writer at the Government Chemical Laboratories, Perth, Western Australia, and grateful acknowledgment is made to the Director of the Laboratories, and to Professor L. J. H. Teakle, University of Queensland, for permission to use the results obtained.

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[American Journal of Science, Vol. 250, November 1952, Pp. 802-807]

"GEFÜGERELIEF" ILLUSTRATED BY "SCHIST TOR" TOPOGRAPHY IN CENTRAL OTAGO, NEW ZEALAND

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ABSTRACT. Throughout much of central Otago, blocky outcrops of schist ("schist tors") are elongated and aligned in a NW to NNW direction. This is parallel to the b(B) axis of the schist fabric. The tor topography reflects the control of differential weathering by rock fabric and so provides an illustration of what Sander has termed *Gefügerelief*.

THE concept of *Gefügerelief*, developed in Professor Sander's latest work on structural petrology (Sander, 1948, pp. 206-208), concerns the topographic expression of rock fabrics. In regions underlain by metamorphic rocks, some elements of the rock fabric—s-surfaces (schistosity), lineations (especially b-lineations in B-tectonites) and joints—may maintain regular orientation over large areas. Moreover, they may so influence the processes of differential weathering and erosion as to become clearly expressed in the topographic detail of the land surface, especially as revealed in air photographs. Sander has applied the term *Gefügerelief* to those elements of topographic relief that can be correlated with rock fabric.

A fine illustration of this phenomenon is afforded by the minor details of the land surface in the central portion of the Province of Otago, southern New Zealand (approximately long. 170°E., lat. 45°S.). The region in question is a basin-and-range province about 3,000 square miles in extent, with topographic relief of about 4,000 feet, and having a varied climate which in the lower levels inclines to aridity. The landscape is treeless; and though the upper slopes of the ranges support a cover of "tussock" grass, vegetation is sparse in the more arid parts of the province.

The oldest rocks are schists which outcrop extensively over the upland surfaces which, over large areas, comprise remnants of stripped plains of erosion cut in early Cretaceous times. Upper Cretaceous and Tertiary sediments still fill the intervening basins. These rocks, too, especially in the vicinity of the east coast have been uplifted and partially truncated by a mid-Tertiary erosion surface which locally overlaps onto the schist terrane and so intersects the early Cretaceous peneplane

(Benson, 1941, p. 209). Present relief is largely the result of Pliocene block faulting. Although climatic conditions must have varied considerably during late Pliocene and Pleistocene times, it should be noted that at no stage within these periods was the central Otago region subject to glaciation.

One of the most characteristic features of the central Otago landscape is the ubiquitous occurrence of "schist tors" over the length and breadth of the stripped erosion surfaces. These tors are isolated blocky outcrops which, over considerable areas, tend to exhibit some regularity of form. They have been described in detail by a number of writers (Finlayson, 1907; Park, 1908, p. 12; Cotton, 1917, pp. 287-289), and their mode of origin has recently been discussed by Raeside (1949) and by Ward (1951). Clearly the tors are products of differential weathering; and Raeside and Ward both emphasize the importance of pre-Miocene weathering of the Cretaceous erosion surface in this connection.

Several generalizations pertinent to the present discussion have been noted by previous writers:

(1) Tor topography is confined to areas of strongly foliated schist and does not develop on adjacent surfaces eroded in greywacke or imperfectly foliated semischists (cf. Cotton, 1917, p. 288; Ward, 1951, p. 195).

(2) Individual tors mostly range from a few feet to thirty feet in height (cf. Cotton, 1917, p. 288, figs. 24, 25), but some are much larger than this.

(3) A rudely rectangular form due to development of boundary surfaces defined by two sets of steep joints is prevalent: and flat-topped tors tend persistently to develop in areas where one of the more pronounced surfaces of schistosity is approximately horizontal (cf. Finlayson, 1907; Park, 1908, p. 12).

(4) Over areas of many square miles tors are elongated and aligned in parallel rows which maintain an astonishingly regular NW to NNW trend, imparting a conspicuous "grain" to the land surface as it appears in an air photograph (Raeside, 1949, fig. 3; Ward, 1951, pp. 193-194, fig. 5). Ward attributes this linear pattern to the presence of parallel belts (perhaps originally strata) of schist differing mutually in their weathering behavior. However, the possibility that original sedimentary

strata persist and maintain such a regular trend in this intensely deformed region cannot seriously be entertained. The parent rocks were massive greywackes in which absence of recognizable bedding is a characteristic feature. Moreover, no geologist has yet succeeded in recognizing within the schist terrane of eastern and central Otago either stratification or formational boundaries distinct enough to allow elucidation of even local structures.

To me the linear "grain" of the schist landscape appears to be a clear example of *Gefügerelief*. The schists of Otago are quartz-rich rocks composed principally of quartz, albite, epidote, muscovite and chlorite. Where a single set of *s*-surfaces (schistosity) predominates it is subhorizontal over large areas. More commonly several sets of *s*-surfaces intersecting in a *b*(B) lineation may be recognized. Banding due to metamorphic differentiation of an initially homogeneous rock into bands alternately rich in quartz-albite and in muscovite-chlorite-epidote is ubiquitous. The most striking and consistent element in the rock fabric is the *b*(B) lineation marked by microfolding of *s*-surfaces and bands, intersection of *s*-surfaces, and girdle orientation of mica, chlorite and quartz (Turner, 1940). It trends NW to NNW with remarkable persistence (fig. 1; see also Turner, 1938, 1940) and is either horizontal or gently plunging. A second lineation with a more northerly trend in some localities intersects the principal *b* lineation. Vertically or steeply dipping joints approximately normal (*ac* joints) and parallel ({*h0l*} joints) to the principal lineation are common and conspicuous.

The following generalizations apply to schist outcrops which I have examined throughout the eastern portion of central Otago:

(1) Individual tors tend to be elongated parallel to the trend of the *b*(B) lineation. In many instances they are terminated abruptly by steep *ac* joints. The rectangular flat-topped form of tor develops in areas where there are steep {*h0l*} joints as well as *ac* joints and where one set of *s*-surfaces is horizontal.

(2) Regional alignment of tors, as illustrated in plate 1, is typically parallel to the trend of the *b*(B) axis of lineation in the schists. There are some areas, however, in which two or more linear elements are blended in the topographic detail of the schist surface. Figure 1 of plate 2 represents such a case. In this particular area, some eight miles east of the town of

Plate 1. Air photograph showing alignment of schist tors about 6½ miles south of Middlemarch, Sutton Survey District, Otago. [Trend of *b* lineation observed in this vicinity is N25°W to N30°W.]

Fig. 1. Air photograph showing distribution of schist tors approximately 8 miles east of Middlemarch, SE corner of Strath Taieri Survey District, Otago. [Trend of main *b* lineation, N30°W; minor lineation N10°W; main *ac* joints strike between N70°E and N80°E.]

Fig. 2. Air photograph of schist terrane with tors poorly developed or absent, SE corner of Hyde Survey District, Otago. [Observed trend of *b* lineation, N35°W to N45°W.]

Middlemarch, the main elements in the megascopic fabric of the schist are as follows (Turner, 1940, p. 180): main lineation *b* trends N30°W; minor lineation trends N10°W; vertical *ac* joints strike N70°E to N80°E. In the left-hand portion of the

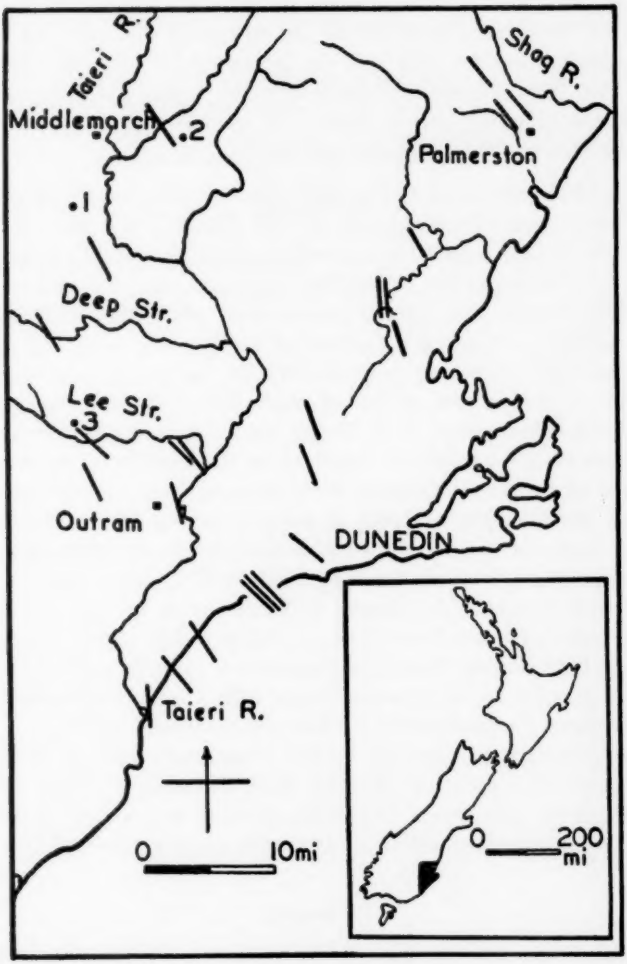

Fig. 1. Map of part of eastern and central Otago, New Zealand. Bars show observed trends of *b*(B) lineations in schists (Turner, 1940, p. 74). Points marked 1, 2, and 3 show respective locations of plate 1 and figures 1 and 2 of plate 2.

photograph a transverse alignment of tors reflects the dominating influence of *ac* jointing. Elsewhere, e.g., near the top right corner, alignment is parallel to one or other of the observed lineations.

(3) In schist country devoid of fully developed tors, a NW to NNW "grain," parallel to the trend of the *b*(B) axis of underlying schists, can still be discerned in some air photographs. This condition is determined by vaguely defined minor features of relief, and is illustrated by the area north of Lee Stream on the Middlemarch road (plate 2, fig. 2).

(4) In some areas the smaller streams consistently conform to trends approximating NW or SW (plate 1 and plate 2, fig. 1), which may reflect the respective influence of *b*(B) lineation and *ac* jointing in the underlying schists.

The topographic details summarized above are here interpreted as constituting a pattern of *Gefügerelief* resulting from differential weathering controlled by the megascopic and microscopic fabric of the schist affected. This pattern, integrated over the schist province of Otago, should give a comprehensive picture of the movements involved in deformational metamorphism of the schist terrane. Data gleaned from rapid scrutiny of air photographs covering an area extending 100 miles inland from Dunedin in a northwest direction, emphasize regional persistence of a *b*(B) axis trending between NW and NNW.

I wish to record my thanks to Professor B. Sander who first demonstrated to me the concept of *Gefügerelief*; and to the John Simon Guggenheim Memorial Foundation for a fellowship which made possible not only consultation with Professor Sander but subsequent re-examination of the schist terrane of Otago. Air photographs were supplied by the Director-general of the Department of Lands and Survey, New Zealand, to whom I am indebted for permission to publish them as well as for facilities for examining many other photographs covering central Otago.

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[American Journal of Science, Vol. 250, November 1952, Pp. 808-821]

SOLID DIFFUSION OF RADIOACTIVE SODIUM IN PERTHITE

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ABSTRACT. The rate of diffusion of radioactive sodium (Na^{22}) in a specimen of perthite was measured (the experimental techniques are described). The results of the experiment are somewhat contrary to expectation, for concentration does not seem to be the sole driving force in diffusion. The facts may perhaps be explained, however, by the influence of environment (here albite and microcline lamellae) on the chemical potential of the tagged sodium ions. Variations in the concentration of mobile ions near igneous contacts may perhaps be explained similarly, as a further example of the influence, at least in part, of chemical potential upon the mobilities of ions in different environments.

The diffusion coefficient of Na^{22} in microcline-perthite varies about the values 10^{-11} and 10^{-12} cm^2/sec. at a temperature of 550°C.

INTRODUCTION

THERE has been much disagreement concerning the geological and mineralogical importance of solid state diffusion. Geological authorities have based many contradictory hypotheses upon their interpretations of the field evidence. There have been, however, very few fundamental laboratory investigations of the problem.

The recent availability of radioactive nuclides has been one of the greatest stimulants to the study of diffusion. This has been especially true in the specialized crystallographic case of metals but, unfortunately, the study of diffusion in minerals, ionic-bonded minerals in particular, lags far behind the bountiful metallurgical literature on diffusion in metals.

A recent study was begun with the hope of shedding further light on this subject (Jensen, ms.). A portion of that investigation dealt with the rate of solid diffusion of radioactive sodium in microcline-perthite. The results obtained in one specimen were rather enigmatic but of enough significance to be presented with some comments and a possible explanation based upon thermodynamic reasoning.

DIFFUSION FUNDAMENTALS AND MATHEMATICAL TREATMENT

Diffusion may be defined as the process by which, under the influence of a concentration gradient and/or a chemical potential gradient, atoms or ions move from one position to

another within a solvent phase. When the phase is a gas, a liquid, or a solid, the diffusion process is more closely defined by the modifying adjectives gaseous, liquid, or solid, respectively.

Solid diffusion rates have been described as varying from fast to slow and from enormous to insignificant, adjectives which are rather nonquantitative. It is, therefore, extremely desirable to place the results of diffusion studies upon a mathematical basis. Such a basis is provided by Fick's Laws (Fick, 1855). According to Fick's First Law the amount of material (dm) per unit time (dt) which diffuses in a direction (+ x) is proportional to the cross-sectional area (A) through which it passes and to a driving force $\left(\frac{\partial c}{\partial x}\right)$, usually thought of as a concentration gradient.

That is: $$\frac{d\,m}{d\,t} \propto A\left(-\frac{\partial c}{\partial x}\right) \qquad (1)$$

A proportionality constant (D) is introduced giving:

$$\frac{d\,m}{d\,t} = -D\,A\left(\frac{\partial c}{\partial x}\right) = -D\,A\,g \qquad (2)$$

where, $\frac{d\,m}{d\,t}$ = rate of transfer of solute

D = diffusivity or diffusion constant

g = concentration gradient.

In order that the units in equation 2 should agree, D must be expressed in units of area/time. In solid state diffusion, it is most commonly given in the units of cm^2/ sec. The diffusion coefficient, therefore, is the amount of solute per unit time which diffuses through a unit cross-sectional area under a unit concentration gradient. D values obtained from the study of diffusion in metals vary from 10^{-5} cm^2/sec. to less than 10^{-15} cm^2/sec. at temperatures ranging from a few hundred degrees to over 1500° C. (Mehl, 1936). A diffusion coefficient of 10^{-6} cm^2/sec. for a specific solute in a solvent means that one gram of the solute diffuses through an area of one square centimeter of the solvent in one million seconds.

Fick's Second Law expresses the relation between the time

rate of change with concentration and the distance rate of change with concentration. It is usually written as follows:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2} \text{ where } D \neq f(c) \qquad (3)$$

$$\text{or,} \quad \frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(D \frac{\partial c}{\partial x}\right) \text{ where } D = f(c) \qquad (4)$$

When the boundary conditions of a given diffusion experiment are known, the differential equation may usually be solved.[1] The resulting equation used for the particular boundary conditions of the experiment to be described in this paper was first applied to diffusion studies in an investigation of the self diffusion of silver (Johnson, 1941). The equation is:

$$C_x = \frac{Co \cdot a}{\sqrt{\pi \cdot D \cdot t}} \cdot e^{-\frac{x^2}{4 D t}} \qquad (5)$$

where, C_x = concentration of radioactive atoms at a distance x from the interface
D = Diffusion coefficient
t = time
Co = Initial concentration of radioactive atoms
a = Thickness of solute film.

It should be noted that the equation is based upon Fick's Second Law with the geometrical boundary conditions specifying that the solute be placed in crystallographic contact with a planar surface of the solvent (fig. 1). The thickness of the solute film should theoretically approach zero but practically it may be as much as five to ten percent of the measurable diffusion distance, a distance usually somewhat less than 0.01 mm. With proper techniques, however, it is fairly simple to keep the distance well within one percent of the measurable diffusion distance.

After a given diffusion time, successive sections are cut from the specimen at known distances from the solute film and the concentration of the solute is determined in each section.

[1] Unfortunately, the diffusion equations which have been used in the past and which are still being used (there is at least one notable exception referred to as the Matano Analysis) were derived with the assumption that $D \neq f(c)$.

The equations for the concentration of two sections (fig. 1) located at a distance x_2 and x_1 from the solute layer are:

$$\text{Section 2:} \quad \ln Cx_2 = \ln \frac{Co \cdot a}{\sqrt{\pi \cdot D \cdot t}} - \frac{x_2^2}{4\,D\,t} \tag{6}$$

$$\text{Section 1:} \quad \ln Cx_1 = \ln \frac{Co \cdot a}{\sqrt{\pi : D : t}} - \frac{x_1^2}{4\,D\,t} \tag{7}$$

The difference is:

$$\ln(Cx_2 - Cx_1) = \frac{1}{4\,D\,t}\left(-x_2^2 + x_1^2\right) \tag{8}$$

Therefore,

$$-\frac{0.1086}{D \cdot t} = \frac{\log (Cx_2 - Cx_1)}{x_2^2 - x_1^2} \tag{9}$$

Since the data are plotted on semi-logarithmic paper with the concentration plotted logarithmically against the distance squared, the right side of equation 9 is the slope of the line as shown in figure 1. If the experimentally determined points give a straight line, the slope may be determined graphically and the diffusion coefficient will be given by equation 10.

$$D = -\frac{0.1086}{\text{slope} \times t} \tag{10}$$

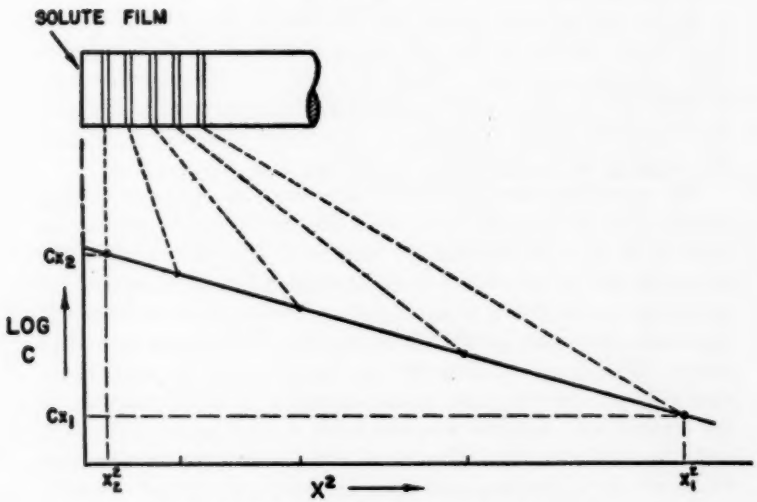

Fig. 1. Plot of concentration versus distance.

If the time of diffusion (t) is measured in seconds and the distances are measured in centimeters, the diffusion coefficient will have the dimensions of cm^2/sec.

EXPERIMENTAL METHOD AND TECHNIQUE

A cylindrical specimen of microcline-perthite was drilled from a suitable larger specimen. Care was exercised in selecting a specimen with no apparent cracks or flaws; however, crypto-flaws such as minute fractures, lineage structure, and impurities could hardly be avoided. The final dimensions were 0.271 inches diameter and about ¾ inches long. One end of the cylinder was prepared as a planar surface normal to the axis of the cylinder.

In order to perform diffusion experiments, it is necessary that the solute, or diffusing ions, be placed in a position where they may readily begin diffusion through or exchanging position with the solvent. This requires that the solute and the solvent atoms be within "atomic reach" of each other; i.e., not separated by a gap of the order of more than a few Ångström units. This is rather easily accomplished in the study of diffusion in metals by welding or electroplating the solute metal to the solvent metal. These methods, of course, are not applicable to ionic bonded minerals.

In this experiment, a thin slip coating of Na_2CO_3 containing Na^{22} was applied to the planar end surface of the cylinder, dried at a temperature of 110° C., and fired at a temperature of 800° C. for five minutes, sufficient time to allow a glaze to form. Examination of samples so prepared indicated that there was negligible initial diffusion during the preparation.

The specimen was then sealed in a capsule of vycor tubing, placed in a furnace which was controlled at a temperature of 550 ± 5° C. and allowed to remain at this temperature for 25 hours and 5 minutes. Upon removal from the furnace, the specimen was partially inserted into a brass collar which would clasp the specimen firmly when carefully tightened in a drill chuck. This even binding about the perthite prevented the chuck from crushing the brittle mineral. A small portion of the cylindrical surface was removed, using emery paper, in order to eliminate the influence of surface and vapor diffusion. Disks of size 1 emery paper were pressed into special capsules which were also used as containers of the active material during the radioactive counting stage. When the capsules were brought

into contact with the planar end surface of the revolving specimen a small amount of material, approximately one milligram, was ground from the perthite. The remainder of the specimen was then weighed and the thickness of the section determined by measuring the decrease in length using micro-calipers. Since the width of each section removed was of the order of a few thousandths of a millimeter and the micrometer was calibrated to read to 0.01 mm, it was found to be much more accurate to plot concentration against the weight of a section removed instead of against thickness. The total thickness removed was recorded however.

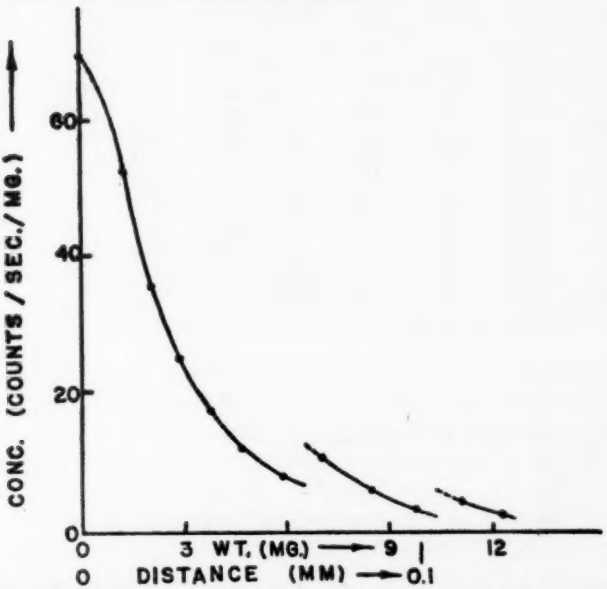

Fig. 2. Variation in concentration of Na^{22} vs. distance into perthite.

During the grinding process, many of the silicates may give off extremely fine powder, which undoubtedly contains some active atoms that may be inhaled. To eliminate this hazard, the base of the capsule was covered with approximately 0.4 cc of alcohol. This prevented dust from rising during the grinding, and the alcohol evaporated soon after the sectioning had been completed.

EXPERIMENTAL RESULTS

The results of the experiment are tabulated in table 1. These results are expressed graphically in figures 2 and 3.

It is significant to notice that the log c versus distance squared curve (fig. 3) is not a straight line as predicted and expected from theoretical considerations. The diffusion coefficient obtained at the temperature of 550° C. varies somewhat about the values 10^{-11} and 10^{-12} cm^2/sec.

TABLE 1
Experimental Data

	Weight				Counting			
Section	Weight of Section (mg)	Center to Center (mg)	Interface to Center (mg)	[I-C]^2 [mg]^2	Counts	Time (sec.)	Counts per Second	Counts per Second per mg.
1	1.78	....	.....	.....	4096	33.1	123.6	69.5
2	0.74	1.25	1.25	1.56	4096	104.8	39.1	52.8
3	0.78	0.76	2.01	4.03	4096	146.3	27.9	35.9
4	0.84	0.81	2.82	7.94	4096	190.1	21.5	25.6
5	0.95	0.89	3.72	13.8	4096	246.3	16.6	17.5
6	0.91	0.93	4.64	21.6	4096	361.5	11.3	12.4
7	1.42	1.16	5.81	33.8	4096	349.7	11.7	8.26
8	1.13	1.28	7.09	50.2	4096	359.1	11.4	10.1
9	1.46	1.31	8.40	70.6	4096	447.7	9.1	6.26
10	1.28	1.37	9.77	95.8	4096	949.9	4.3	3.36
11	1.28	1.28	11.05	122.0	4096	710.0	5.8	4.50
12	1.15	1.22	12.26	150.0	2048	674.7	3.0	2.64

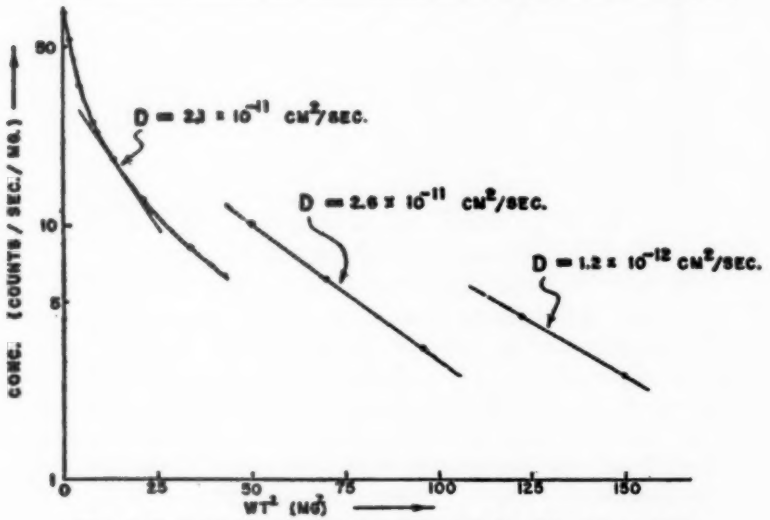

Fig. 3. Concentration vs. distance squared for diffusion of Na^{22} into perthite.

DISCUSSION OF RESULTS

The concentration against distance curve obtained (fig. 2) was not expected, but there seem to be several possible interpretations.

Consider two end members, A and B of a binary system which are placed in juxtaposition, and a third component, solute C, which is applied to a planar surface parallel to the interface planes of A and B (fig. 4). If a diffusion run is made at a temperature where A and B are not in solid solution, the resulting concentration-distance curve will show a sudden rise at the A-B interface if the diffusion coefficient of solute C in member B has a lower value than the diffusion coefficient of solute C in member A. If the coefficient were reversed (solute C diffusing through B more rapidly than through A) there

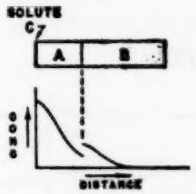

Fig. 4. Diffusion of solute C in members A and B.

would then be a sudden decrease or fall of concentration at the interface of A and B. It is possible that the result obtained from diffusion of sodium into the perthite specimen is analogous to the above consideration. The perthite specimen used consisted of thin laminae of albite and microcline which, roughly speaking, can be considered to be end members of the $NaAlSi_3O_8$-$KAlSi_3O_8$ binary feldspar system. The diffusion temperature of 550° C. might be in a region of solid solution (Bowen and Tuttle, 1950); however, the diffusion run probably allowed insufficient time for mixing to occur, especially since it took place under conditions of atmospheric pressure and no water vapor.[2] The analogy, however, now becomes less clear. The

[2] Bowen and Tuttle have given quantitative data on the rates of unmixing and mixing of cryptoperthites and have noted the significance of increased rates of diffusion in perthites under pressure of water vapor. They state that, "if any feldspar is held at a temperature where it should form two feldspars, as indicated by the solvus, unmixing will occur in a period of a few days *if* [italics mine] water vapor under pressure is present to facilitate mobility."

perthite consists of numerous alternating lamellae of the two end member components, whereas the example (fig. 4) of the A and B end members consists of only one specimen of each member. The numerous interfaces between the microcline and the albite were, furthermore, not parallel to the thin solute film but intersected the plane at an angle of approximately 30 degrees. During the sectioning, different ratios of microcline to albite were removed due to the nonuniform width of the lamellae and the general variation of the ratio of albite to microcline from place to place in the perthite. It appears (figs. 2 and 3) that the ratio may have shown a somewhat continuous variation from the interface through a distance into the specimen of about 0.065 mm. At this position and again at a distance of about 0.103 mm, the ratio may have varied rather abruptly. It seems possible that the sodium tended to diffuse through one of the two members at a more rapid

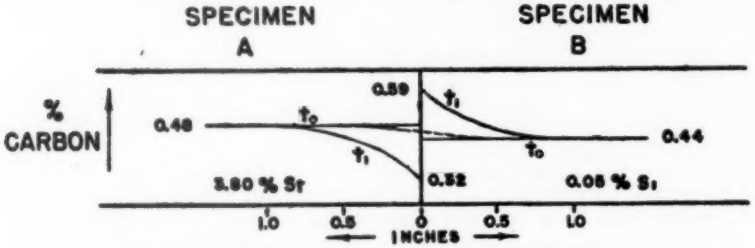

Fig. 5. Diffusion of carbon in steel (from Darken).

rate. Therefore, when a section was removed containing less of the component through which diffusion is more rapid, the concentration of radioactive sodium in that section was higher.

This reasoning seems rather vague if concentration is the sole driving force for diffusion, but according to the definition of diffusion given in the first portion of this paper, the driving force may be concentration and/or chemical potential. In an enlightening experiment, however, Darken (1949) investigated the solid diffusion of carbon in two specimens of austenite steel which were joined together along a planar contact. One specimen contained 3.80% Si, and 0.478% C; the second contained 0.05% Si and 0.441% C (fig. 5). If the concentration gradient is the driving force, one would expect that during diffusion the carbon concentration would approach the concentration shown by the dashed line (fig. 5); the concentration, however,

after a diffusion time t_1 was found to vary as shown by the diagram. Since carbon has a higher than normal chemical potential when in the presence of silicon, the carbon atoms tend to move about more rapidly in the austenite steel specimen having the higher silicon content, and more carbon atoms move across the interface from left to right (from specimen A to specimen B) than in the opposite direction. Hence, after an initial diffusion period, the concentrations of carbon on the two sides of the interface become more and more divergent during diffusion.

Possibly, therefore, the sudden "jumps" in the sodium solute concentration curve are due to unequal amounts of a component in the microcline and albite lamellae, possibly even some impurity, which would vary the chemical potential of sodium. In fact, the difference in the ratio of initial sodium and

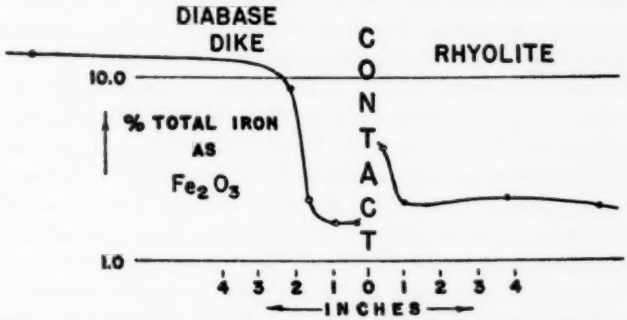

Fig. 6. Concentration of iron across igneous contact (from Dennen).

potassium in the two components might be the cause of the effect. As a result, the sodium ions would tend to diffuse more rapidly in that material or mineral having the higher chemical potential for sodium.

Geologic contacts and even the notorious basic front may be other examples of the effect of thermodynamic potential on diffusion rates. Dennen (1951) has presented curves (fig. 6) showing the variation of mobile ions across igneous contacts. He has often observed that the concentrations of an element on the two sides of a contact become divergent as the contact is approached. In the light of Darken's work it seems that a concentration variation curve such as this may be due in part to the effect of chemical potential on the mobility of ions near

igneous contacts. The mobile (iron) ions (fig. 6) may have a higher chemical potential value in the diabase than in the host rock or rhyolite. As a result of this, more of the element moves across the contact to the right and the concentration near the contact within the rhyolite is increased as shown.

The granitizers should, however, be wary of reading out of this experiment a mechanism for forming zoned crystals by solid diffusion. It is true that sharp changes in concentration of certain mobile ions may occur within crystals by this means, but it should be remembered that the ion or ions causing the thermodynamic effect will also tend to move about in the solid state with the result that homogenization of the system may eventually be reached.

Some might be rather disappointed if no speculations on granitization were presented here pertaining to the diffusion coefficient obtained from this study of diffusion of radioactive sodium in feldspar. The curve (fig. 3) indicates that the diffusion coefficient is of the order of 10^{-11} to 10^{-12} $cm^2/sec.$ at a temperature of 550°C. These quantitative results are of the same order of magnitude as those obtained by Rosenqvist (1949), and those we have been told to expect by Bowen (1948). Actually, the concept of rather large channelways through the structure of a crystal, usually a silicate, which allow an ion practically to fall through them is perhaps a misconception. Rather, it seems that these passageways are more aptly described as a series of cages containing the diffusing ion, with fairly large interconnectng openings. The size of these openings is of less importance than the potentials about each cage. Even though a polymorphous mineral may acquire larger and larger channelways with increase in temperature, the total expansion in the size of the cages forming the passageways is of the order of about one Ångström unit, usually much less. This rather insignificant expansion does not noticeably decrease the potential barriers existing about each cage for the diffusing ions. The result is that the bond strengths are not decreased appreciably by expansion, even though they do vary as the reciprocal of the square of the distance, and diffusing ions still have some difficulty in overcoming the bond strengths and jumping rather rapidly from one cage to another. This difficulty in overcoming electrostatic repulsions and attractions is encountered even in undercooled liquids, such as glasses,

which contain very large cages and openings. The diffusion coefficient of sodium migrating through sodium glass is as low as 10^{-8} cm^2/sec. at a temperature as high as 850° C. (Johnson *et al.*, 1950).

Rosenqvist (1949) has obtained diffusion coefficients varying about 10^{-8} and 10^{-9} cm^2/sec. for diffusion of Ra^{++} in albite at temperatures very near the melting temperature of albite. Of course, it is important to realize that these values might easily be increased by other factors such as pressure (especially in feldspar crystals under high water vapor pressure), impurities, and application of a potential across the minerals in order to "pull' the solute ion through the crystal. There is little doubt, furthermore, that diffusion rates through fractures and openings in rocks and minerals are of much greater importance.

The suggested explanation of the "jumps" in the curve (fig. 2) should not pass without further scrutiny. It is certainly possible that many other explanations can be offered. If diffusion were more rapid along boundary zones between the lamellae, localization of tagged sodium atoms in these zones would result in an irregular concentration versus distance curve. Autoradiographic techniques could be applied in studying this possibility. Some studies already made on the importance of grain boundary diffusion in different materials have given various conclusions. In some cases (Martin *et al.*, 1949) grain boundary diffusion was found to be negligible while in other studies (Langmuir, 1934) it was found to be of major importance. Very little, of course, is known about grain boundary diffusion of sodium in perthite, or in other silicates for that matter.

CONCLUSIONS

It is rather difficult to arrive at undisputed facts when experimenting with minerals, which are, according to their definition, "naturally occurring products," which means that impurities and unknown constituents may be present on the order of several percent. Wagner (1950) has already shown the tremendous effect of impurities on diffusion rates, and it appears that rather larger variations in diffusion rates occur in various specimens of chalcocite (Jensen, ms.). Rosenqvist (written communication, Nov. 11, 1950), furthermore, has

noticed that diffusion rates of Pb and Ra in feldspars vary considerably from specimen to specimen.

There is no doubt that the experiment should be repeated by applying the thin solute film of radioactive ions over a plane which is essentially parallel to the albite-microcline interface planes. In this manner the correlation, if any, between the jumps and the lamellae may be ascertained.

There has been no intention of presenting these results in a dogmatic fashion but rather as a description of an interesting experiment which led to a further search in the literature for a plausible explanation of the results.

ACKNOWLEDGMENTS

I am especially grateful to the Departments of Geology, Metallurgy, and Physics, Massachusetts Institute of Technology, for providing equipment and materials needed to perform this investigation.

I am indebted to both Prof. M. J. Buerger and Prof. C. Wagner who first kindled my interest in the subject of mobility of ions in solids, and who also supplied invaluable aid in discussion and solution of theoretical and practical problems encountered in investigations on this subject.

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[American Journal of Science, Vol. 250, November 1952, Pp. 822-828]

A MEGABRECCIA FORMED BY SLIDING IN SOUTHERN FRANCE

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ABSTRACT. In the south of France amidst the Tertiary plain of Alès a series of hills is found built up of a breccia of Urgonian and Hauterivian limestones, lying disconformably upon Lower Tertiary. The occurrence appears to be analogous to the occurrence of a megabreccia in Nevada and Arizona, described by Longwell (1951), the origin of which is explained by sliding. This principle can also be applied to the breccia found in France.

INTRODUCTION

IN the Tertiary plain of Alès in the south of France a series of hills is situated, built up of a breccia of Lower Cretaceous limestones and marls (fig. 1). These hills have been studied by French geologists since 1880. Apart from some conceptions out of date, there were two quite different theories about the origin of this breccia. During the summer of 1951 the author spent three months in the area in order to test by detailed mapping the existing theories.

Longwell (1951) describes the occurrence of large remnants of megabreccia in southern Nevada and western Arizona. As there appears to be, irrespective of the age of the formations, a striking similarity between the occurrence of Longwell's megabreccia and the breccia-occurrence in the south of France, Longwell's observations will be briefly quoted first, and at the end of this paper an attempt will be made to apply his explanation to the breccia in the plain of Alès.

OCCURRENCE OF MEGABRECCIA IN WESTERN ARIZONA

According to Longwell the breccia is exposed in an area about 6 miles long from northwest to southeast, with maximum width nearly 3 miles and lying upon Tertiary lavas and Miocene basin deposits. On the eastern side the area is bordered by the high ridge of the Black Mountains, composed of Precambrian gneiss, schist and granite. The entire mass of typical breccia consists of broken rock. Some individual fragments are hundreds of feet long; there is no matrix of clay or other fine-grained weathering products. The fragments making up the breccia were derived from Precambrian bedrock—gneiss, schist and granite like those in the Black Mountains complex, which is the one

logical source of the debris. In general the body of breccia, up to several hundreds of feet thick, is unassorted and wholly chaotic. The underlying Miocene silt, gypseous clay and gravel beds are remarkably little disturbed. At a few localities only

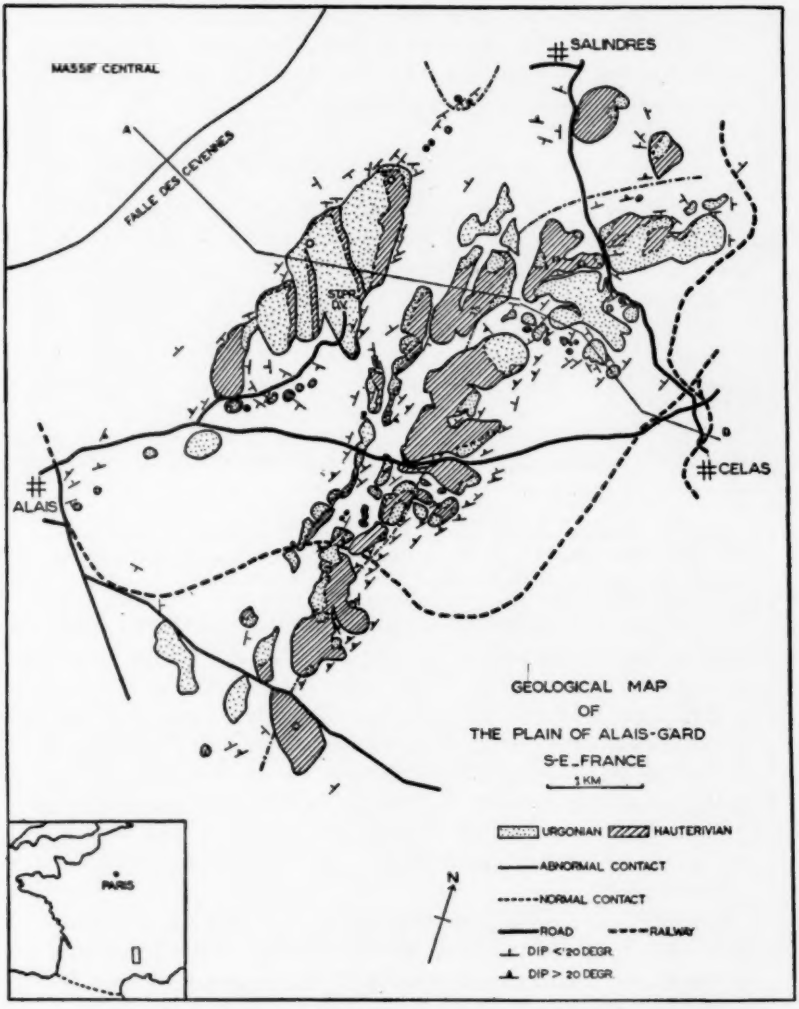

Fig. 1. Geological map of the Tertiary plain of Alès, showing the Hauterivian and Urgonian breccia. A-B, line of section, figure 2.

the layers directly beneath the contact with the breccia are crumpled. Commonly the contact surface is smooth and carries striae, trending generally with the slope.

The west base of the Black Mountains is marked by a zone of faulting, with upthrow of the Precambrian block on the east.

The coarse debris of Precambrian rock was derived from the Black Mountains, as indicated by its distinctive lithology, and is interpreted as a landslip mass, the front of which moved at least 5 miles from its bedrock source.

OCCURRENCE OF MEGABRECCIA IN SOUTHERN FRANCE

The plain of Alès is a fault graben with maximum width of 7 kilometers (4.4 miles) and extending in a NNE-direction for about 45 kilometers (28 miles) parallel with the eastern border of the crystalline "Plateau Central" (Cevennes), which is covered by Carboniferous, Triassic, Jurassic and Lower Cretaceous deposits (figs. 1, 2). This massif is separated from the plain by a fault system, mainly consisting of normal

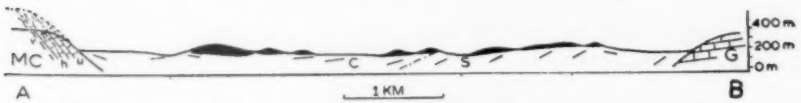

Fig. 2. Geologic section along A-B, figure 1. Vertical scale same as horizontal. MC, Massif Central; G, Garrigues; black, breccia; v, Valanginian; h, Hauterivian; u, Urgonian; C, Chattian; S, Stampian.

faults, called "Faille des Cevennes," which has a NNE-direction. The breccia in the southern part of this extensive plain is found only over a distance of about 11 kilometers (7 miles).

The Lower Cretaceous covering the eastern border of the Plateau Central consists of Valanginian marls and Hauterivian limestones and marls, characterized by *Toxaster amplus*, being therefore indicated in French literature as "Marnes à Toxaster" (M.à.T.). The M.à.T. are overlain by white and yellow Barremian limestones (Urgonian facies). These limestones are hard and compact.

This M.à.T. and Urgonian builds up a NNE-ridge, which rises more than 130 meters above the Tertiary plain. The whole of the Lower Cretaceous has a dip of 45 degrees to the southeast, i.e., valleyward.

At the eastern border of the Plain of Alès are situated the

PLATE 1

Fig. 1. Detail of breccia of Urgonian limestone. Note striae on the block to the right and angular form of the block to the left.

Fig. 2. Section along the railway in the middle of the plain of Alès, showing undisturbed bedded Oligocene gravels and marls in the foreground (right) overlain directly by the chaotic breccia of Urgonian limestone in the background (left).

View, looking north, of one of the hills, built up of the breccia of Urgonian limestone, in the midst of the flat Tertiary plain. In general there is a gentle dip slope to the west and a steep wall to the east. In the left background the breccia hill of Saint Privat des Vieux can be distinguished and in the right background another series of hills of the same breccia.

Garrigues, separated from the plain by a fault system. The Garrigues consist of Lower Cretaceous limestones which have been intensely folded during the Eocene perpendicular to the fault system. The fault-graben of Alès between the Plateau Central and the Garrigues is filled with Oligocene sediments (gravels and marls) which all dip 10° to 30° westward. There are some counterdips, which may be explained, as shown later, by the emplacement of the overlying breccia mass.

The highest part (Chattian) of the Lower Tertiary deposits in the graben of Alès contain mainly Urgonian pebbles, and the lowest part (Stampian) contain also quartz and schist pebbles. The boundary between these two formations is indicated on the map by a dot-dash line.

In the middle of the fertile and cultivated plain are situated a great number of hills and ridges (one hundred meters high), built up of the breccia of Urgonian limestones and layers of M.à.T., which are brecciated too. Since 1880 French geologists have tried to give an explanation for this more or less strange occurrence of hillocks of Cretaceous limestones and marls in the midst of the Tertiary plain. Some believed these hills were the tops of islands piercing through the overlying Oligocene. In 1919 Termier and Friedel considered the hills as remnants of an overthrust mass, that would have covered the whole area. On the geological map they are still called "klippes" and the breccia is compared with a mylonite. This theory is now abandoned by all geologists.

More recent investigations have been executed by G. Denizot (1931, 1937) and J. Goguel (1936). Denizot divides the occurrence of the breccia mass into two groups, namely the big hill of Saint Privat des Vieux (a village) and the small hills to the northeast and southwest of it in the western part of the plain on the one hand, and the row of hills in the eastern part on the other (fig. 1; plate 2). Denizot assumes that the breccia mass of the hill of St. Pr. d. V. has a root. In other words it is piercing through the Oligocene. The same would apply to the small hills.

After exhaustive fieldwork in 1951 the author cannot agree with this opinion and believes the mass (about 50,000,000 cubic meters) is lying upon the Oligocene. The main facts upon which his opinion is based are: 1) Along the western border of the hill the Tertiary dips under the breccia; the contact is clearly

visible. 2) There are two windows, one on the northern and one on the western part of the hill, in which the Oligocene is exposed beneath the Cretaceous breccia. 3) If we had to do with bedrock in place, the superposition Urgonian/Hauterivian would be maintained rigorously. Near the village St. Pr. d. V. one can observe, however, that the breccia, mainly consisting of Urgonian limestone, contains among these blocks also big blocks of Hauterivian limestone. 4) Denizot himself mentions a drilling in the Tertiary, which was executed between the hill of St. Pr. d. V. and the small hills southwest of Salindres. At a depth of 260 meters the Cretaceous was not yet reached, so if these hills were the tops of islands, the slopes must be very steep (at least 45°). In the eastern part of the area Denizot considers the breccia masses as bedrock in place too, but to explain the superposition of the breccia upon the Tertiary over a distance of more than one kilometer he assumes the existence of thrust faults of low angle (less than 30°). In my opinion, the superposition of Cretaceous breccias upon the Oligocene deposits can be followed over a distance of more than four kilometers from west to east, or over the whole breadth of the occurrence.

The author can agree with the opinion of J. Goguel (1936), to the extent that the latter does not consider the breccia as bedrock in place. However, Goguel assumes that the breccia of Urgonian limestone is interstratified in the Oligocene. Goguel assumes for the hill of St. Pr. d. V. that the breccia is lying upon the Oligocene. He connects the hills in the eastern part of the area in such a way, that they belong to four layers of a breccia of Urgonian limestone, which are interstratified in the Oligocene, and which could be followed over a distance of some kilometers. So according to Goguel the breccia is sedimentary. The difficulty for Goguel is to find the origin of the elements of the breccia and the way of transport by which the normal sedimentary process was interrupted at least four times by the deposition of these breccias. Because blocks of many tons are not rare, neither river transport nor a mudflow can be responsible for the sedimentation. Glacial transport is excluded also.

Finally Goguel ventures to remark that on the western side the plain is bordered by a fault system, which was active during the deposition of the Tertiary. There might be a certain rela-

tion between the sudden affluence of the brecciated Urgonian and the different periods of activity of the fault.

Now the author's observations will be briefly summarized. All over the area the brecciated Urgonian and Hauterivian limestones and marls are lying more or less unconformably upon the Tertiary. There is no reason to separate the hill of St. Pr. d. V. from the hills in the eastern part. So, we have nowhere to do with bedrock in place. Neither is there any reason to connect the different hills in order to get continous layers of breccia. Although erosion will have removed part of the original mass, it is very questionable if there has ever been a continuous covering. Mostly the breccia is wholly chaotic (plate 1, fig. 1 and fig. 2), although to a large extent the superposition Hauterivian/ Urgonian is maintained. The discrete blocks of various sizes are imbedded in a matrix made up of small fragments, all of the same Cretaceous formations. The breccia ranges up to 40 meters thick, but commonly the thickness is less. In some places the Urgonian lies directly upon the Oligocene gravels and the M.à.T. are missing. The large fragments at the lower part of the breccia carry striae, trending generally with the slope (plate 1, fig. 1). The underlying Oligocene marls and gravels are somewhat disturbed. Although in general the dip of the Oligocene is to the west (10° to 30°), there are some counterdips in the eastern part of the area in front of the breccia masses, which must be explained by thrusting. Perhaps the eastward dip along the western side of the hill of St. Pr. d. V. can be explained by compaction of the Tertiary under the weight of the overlying breccia mass.

CONCLUSION

Thus there is a striking similarity between the occurrence of this breccia and the occurrence of the breccia described by Longwell. The only logical source of the brecciated material is the Hauterivian and the Urgonian bedrock of the Plateau Central. Because the dip of the formations there is very steep (45°) plainward, it can be assumed that the breccia masses in the plain originated by landslides of material shed from the relatively rising Cevennes. The Hauterivian marls served as a lubricant. In the plain one can observe numerous recent small-scale landslides of Urgonian breccia over Hauterivian marls. Whether we have to do with a chronic or a catastrophic slide

is doubtful. In this respect the great Turtle Mountain slide at Frank Alberta in 1903 (C. F. Stewart Sharpe, 1938) is very suggestive. The mountaintop stood some 3100 feet above the valley and was composed of massive limestones thrust over a much younger and softer series of sandstones and shales. Movement was initiated on a well-developed system of joints, which dipped valleyward at an angle of about 40 degrees. The rock-slide-rockfall rushed across the valley over a distance of 2.4 miles (4 kilometers) and 400 feet (122 meters) up the opposite wall. It is estimated to have carried down 35 to 40 million cubic yards of rock (26 to 30 million cubic meters). The quantity of breccia now present in the plain of Alès is estimated to be 150 to 225 million cubic meters, and has been spread across the Tertiary plain of Alès over a distance of at least 2.4 miles (4 kilometers). Whether or not we have to do with a sudden or with a chronic sliding cannot be said for certain, yet there cannot be any doubt about the slide origin. In this slide the stratigraphical sequence of the rocks has not been disturbed, apart from local imbrications and wedging out of the marls at the base. Urgonian limestone breccia is still resting on top of the Hauterivian marls.

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[American Journal of Science, Vol. 250, November 1952, Pp. 829-833]

SEA LEVEL AND THE ROTATION OF THE EARTH*

WALTER MUNK AND ROGER REVELLE

ABSTRACT. From ancient beach lines, Daly has proposed a eustatic lowering of sea level by about five meters during the last few thousand years. This would decrease the length of day by 30 milliseconds if the lowering is due to "rapid" growth of ice caps, and by 90 milliseconds if, as suggested by Daly, the lowering is due to isostatic afterflow in the earth's mantle following a rapid melting of ice caps. The corresponding value derived from ancient observations of eclipses, 27 ± 18 milliseconds, indicates rapid growth of ice caps.—For the last hundred years, tide gauge records and the retreat of glaciers indicate a *rise* in sea level by 10 cm. This rise would displace the north pole of rotation by something like 10 feet towards the North Atlantic, the precise value and direction depending on the source of melted water. Such a displacement is not inconsistent with astronomic evidence.

SUPPOSE the melting of ice over Greenland and Antarctica causes a relatively rapid rise in sea level over all the oceans. This will have two effects on the earth's rotation: because of the resulting increase in the earth's moment of inertia its angular velocity will diminish (i.e., the length of day increase); and on account of the asymmetrical distribution of land and sea, the axis of instantaneous rotation will be tilted. The numerical values in table 1 have been computed under the three stated assumptions concerning the source of the melted water (Munk and Revelle, in press). The values allow for the elastic yielding of the earth.

TABLE 1

The increase, τ, in the length of the day, and the displacements (λ, towards Greenwich; μ, towards 90° east of Greenwich) of the north pole of instantaneous rotation, resulting from a rapid rise in sea level by z cm. A: the rise is caused by melting on Antarctica only; A and G: equal melting per unit area over Antarctica and Greenland; G: melting on Greenland only.

	A	A and G	G
τ/z in milliseconds per cm	0.06	0.06	0.06
λ/z in feet per cm	0.00	0.28	2.22
μ/z in feet per cm	−0.32	−0.49	−1.63

The altered distribution of matter will induce an isostatic afterflow which will last for T years after the rapid rise in sea level has ceased. For Fennoscandia, T is rather less than 10,000

*Contribution from the Scripps Institution of Oceanography, New Series, No. 592. This work has been supported by the Office of Naval Research, and by a grant-in-aid from the Institute of Geophysics, University of California.

years (Gutenberg, 1941). Material slightly denser than 3 g cm^{-3} will flow within the earth's mantle from regions beneath the oceans to regions beneath continents from which ice has been removed. The flow will be accompanied by a decrease in the length of day, and a reverse movement of the pole of rotation. The sea bottom, and with it the sea surface, will eventually drop by about one third the amount of the initial rise in sea level. For a drop in sea level by z cm during this interval, the numerical values are roughly three times those in table 1, and of opposite sign.

In this discussion, the term "rapid" has referred to a time interval short compared to the "relaxation time" T. If a rise is sustained over an interval as long as or longer than T, the addition of water mass and the removal of mantle material occur concurrently. This is equivalent to an addition of mass at the sea surface, and a corresponding removal beneath the sea bottom. Under these circumstances, the numerical values of τ/z, λ/z, μ/z are greatly reduced compared to those in table 1. The reduction factor is of the order of a/h, where a is the radius of the earth, and h the depth of isostatic adjustment. For h equal to 300 km, a/h equals 20.

The sea level will also rise if the oceans become warmer, even if no ice is melted. An increase in the temperature of all the ocean water by 1°C would raise the sea level by 60 cm! Again this is equivalent to an addition of mass at the surface and a corresponding removal at depth. Numerical values are reduced by a factor of the order of a/h′ compared to those in table 1, where h′ is the depth to which the water is heated. The reduction factor is certainly larger than 1000.

The foregoing relationships are useful in interpreting observations during historic times of changes in sea level and in the earth's rotation. For example, about 3000 years ago, during the postglacial temperature maximum, sea level is believed by Daly (1920, 1927) and others (Kuenen, 1950, pp. 448, 537-539) to have stood approximately five meters higher than it does today. A drop by 5 m. would result in a decrease of the length of day by the following amounts, depending on the condition of lowering:

(1) rapid growth of ice caps	30	milliseconds
(2) isostatic afterflow following rapid melting of ice caps	90	"
(3) slow freezing of ice caps	−1.5	"
(4) cooling of entire oceans by 8°C.	−0.03	"

From an analysis of ancient observations by Greek, Babylonian, Chinese and Egyptian astronomers, Fotheringham (Jeffreys, 1929, p. 255) found that the day has lengthened by 2.0 milliseconds per century in historic times. Subsequently there has been a "secular decrease" in the values given in the literature for the secular increase of the length of day. The most recent investigation by Brouwer (1952), based largely on the comprehensive work by Spencer Jones, gives a secular increase by 1.35 ± 0.55 milliseconds per century during the last 3000 years. A modification by Urey (1952, pp. 80-87) of Jeffreys's theory concerning the effect of tidal friction leads to the result that the observed secular accelerations of sun and moon can be made consistent only if it is assumed that tidal friction accounts for 1.7 times the observed lengthening of the day, and that changes in the earth's moment of inertia make up the difference. The required dissipation of the earth's rotational energy by tidal currents lies within the range of values estimated by Jeffreys. We have, therefore, from astronomic evidence the following changes in the length of day:

due to tidal friction	+2.3 ± 1.6	milliseconds/century
due to moment of inertia	−0.9 ± 0.6	"
total change	+1.4 ± 0.4	"

The values and probable errors follow from Brouwer (1952).[1]

We are concerned here only with the part due to changes in the earth's moment of inertia, i.e., a shortening of the day by 27 ± 18 milliseconds in 3000 years. The probable error is very large; still, some useful information can be gained from a comparison with our calculated values corresponding to changes in sea level under various conditions. The value 27 ± 18 milliseconds is consistent with a rapid growth of ice caps (condition 1), but not with Daly's suggestion of isostatic afterflow following a rapid retreat of ice caps at the close of the glacial period (condition 2). Combinations of conditions

[1] After this note had been in press, Professor Mintz called our attention to an additional effect, first noted by Kelvin (Royal Soc. Edinburgh Proc., 1882, vol. 11, p. 396), which is not included in Brouwer's calculations. It is known from barometric observations that the semi-diurnal component in atmospheric pressure reaches a maximum before noon. The result is an accelerating torque by the sun on the atmosphere. The present estimate of this torque is 3.6 ± 0.2 x 10 dynes cm. The resulting decrease in the length of day by 0.17 milliseconds per century would modify the amount ascribed to the moment of inertia from -0.9 to -0.7 milliseconds per century. In the further discussion we have used Brouwer's value of -0.9 milliseconds per century.

(2), (3) and (4) are also possible. With regard to condition (4), measurements of the temperature gradient in the sea floor (Revelle and Maxwell, 1952) make it unlikely that cooling of the oceans during the last 3000 years has exceeded 5°C. Climatologic studies (Wright, 1914, pp. 384-385) indicate 2°C. as an upper limit for the decrease of the mean surface air temperature. An equal decrease throughout the entire water column would correspond to a sea level lowering of 120 cm. There are, of course, other possible explanations for the changes in the length of day. Urey (1952, pp. 87-89), for example, postulates a rain of mantle iron into the core of the earth.

In more recent times, indications are for a *rise* in sea level. Thorarinsson (1940) extrapolates observed shrinkage of glaciers and estimates a rise by at least 5 cm (possibly 12 cm) during the last century. From tide gauge records, Gutenberg (1941) finds 10 cm during the century. Kuenen (1950, pp. 533-534) obtains about twice this value. The agreement between Thorarinsson's and Gutenberg's values indicates that the deep massive parts of the oceans have participated only slightly, if at all, in the widespread warming of the atmosphere by 1°C. to 2°C. during the last century.

A rise in sea level by 10 cm caused by rapid melting (condition 1) leads to an increase by 0.6 milliseconds per century in the length of day. During the last few hundred years the length of day has varied erratically by much larger amounts. Between 1870 and 1900, for example, it increased by six milliseconds, and between 1910 and 1930 it decreased by four milliseconds (Brouwer, 1952). These changes are so large that they must be due principally to factors other than fluctuations in sea level (Munk and Revelle, in press). At the same time they make it impossible to detect a slow secular trend. In all events, a sea level rise by 10 cm in the last century cannot be ruled out by this astronomic evidence.

Consider now the effect of such a 10 cm rise on the displacement of the pole of rotation. According to table 1, the displacement would be 3 feet towards Chicago, 6 feet towards Newfoundland, or 27 feet towards Greenland, depending on whether the melting occurs on Antarctica, Antarctica and Greenland, or Greenland. The pole of rotation is therefore a remarkably sensitive indicator of the source of melted water. Astronomic evidence in this regard is available only since

1890, and is not considered reliable, but the indication is for a movement by 10 feet towards Greenland between 1900 and 1925 (Wanach, 1927), and little movement thereafter (Markowitz, 1942). The last of the three alternatives, melting on Greenland, is in best accord with regard to both magnitude and direction.

We conclude that astronomic evidence concerning changes in the length of day and the position of the earth's pole of rotation may be useful in interpreting observed changes in sea level during historic times. It is of interest to note that eustatic changes of sea level in geologic times by as much as 1000 meters, even if not isostatically compensated, would change the length of day by only six seconds, and move the pole by 10 miles. Although these changes are a thousand times larger than those that can now be detected by astronomic measurements, still they would not leave a perceptible imprint on fossil records of life and climate.

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ESSAY REVIEWS

Horses; by GEORGE GAYLORD SIMPSON. Pp. xxiv, 247; 32 plates, 34 figs. New York, 1951 (Oxford University Press, $6.50).—If all man's present knowledge and intelligence had been available in early Eocene time for a forecast of the future of eohippus, it is inconceivable that the modern horse could have been predicted. The horse, like man, is a quite improbable product of evolution, and, although these two have been associated for thousands of centuries, it is still less likely that a sixty-million-year history of one should be written by the other. Nevertheless this has happened, and Simpson has added a good and straightforward book to the literature about horses. It is intended to be "a full history of the horse . . . but . . . in broad outline only, with most of the technical details rigorously suppressed."

Between the opening witticism of the introduction and the closing comment that the ultimate explanations of evolution lie beyond the territory of science, the book is divided into three parts: (1) living horses, classification, structure, breeds, influence on human history, gaits, and colors, (2) the search for fossil horses, the time scale of their evolution, ancestors, structural stages, horse relatives, and "false horses," (3) reasons for studying fossil horses, the evolution of the horse head, teeth, limbs and brain, and patterns and explanations of horse evolution. There is an appendix listing the principal exhibits of fossil horses in the United States, a brief and well-chosen bibliography, and a competently-prepared eleven-page index. The pleasing appearance of the book shows careful planning in such important book-making details as color of the paper and the cover and the chart on the end papers.

Simpson obviously wrote for the large class of readers who like and admire horses and he apparently aimed his composition at a level between beginners and specialists. He gives pronunciations for most of the categorical names, occasionally instructs his audience not to bother to read or learn some of the technical sections, and refrains from taking sides on squabbles about origins of living breeds or about taxonomy of fossil forms. He makes it clear that a very proper study of mankind is horses, both living and fossilized, and he doesn't hesitate to make provocative and amusing comments such as "horses have had ancestors as long as anybody," "there is not much point in criticizing nature for something that happened some millions of years ago," "any color is good on a good horse," "*Merychippus,* the horse with the new look, was a sensational success," "the horse is both intelligent enough and stupid enough to do what we demand of him," and "Moral: Do your own dancing and let the horse watch you." It must have been unusually difficult to set the patterns of originality and completeness which characterize this book, because there are already so many articles, books and monographs on horses. Selection of consistent and pertinent material and condensation were major problems but Simpson has

solved them well. Obviously fond of horses, he expresses a warm appreciation of their beauty of form and function and their grace and organic elegance; he also frequently refers to their significance to man in his economic, social, military, cultural, industrial, and political affairs. Moreover, he has successfully used his study of horses to exemplify methods of classification, principles and processes of evolution, concepts of adaptation, origins of domestication, ways that fossils are found and studied, and how a great many related facts are discovered about the earth and organic history.

Among the particularly interesting sections are those on horse gaits and how Muybridge's photographic studies of them led to his invention of the "zoöpraxiscope" which was the forerunner of the present motion-picture projector. Readers will learn about theories of the inheritance of coat color in palominos, about Simpson's first important fossil discovery, and about the lowly origin of Thoroughbreds. He casts several bricks on the grave of the frequently resurrected idea of orthogenesis in horses, brands the breeders' notion of telegony as completely false, and states that native horses were definitely extinct in the Americas before Cortez imported some in 1519.

Simpson uses words with a nice precision and has in general made an excellent compromise between the plain and sometimes monotonous language of scientific exposition and the commonly condemned literary style of "popular science" writing. It is a pleasure to read a geological author who has been careful to use the correct adjectives for nouns that connote time. Many, indeed most, geological writers have confused their readers and themselves by mixing time and object in such terms as "*lower* Eocene," or "*early* Bridger"—phrases that are about as poorly conceived as "lower January" or "early Washington Monument."

Thirty-two plates showing horse morphology, breeds, famous paleontologists, ancestral horses, horse relatives, and "false horses" are assembled at the front of the book. Most of the pictures composing the plates are well chosen and of satisfactory scale, but some of the 34 text figures are not as successful and they raise questions about their selection, captions and size. A few of the figures are mere sketches, poorly and incompletely labeled, and not as informative as they might be.

Some of the errors and oversights in the figures and the text of this first edition will not be hard to correct in future printings. In the caption of figure 2 the words "(left)" and "(right)" are interchanged, as are "(below)" and "(above)" for figure 30. Readers would be helped by statements, for about half of the figures, concerning the scale of reduction or the sizes of the objects represented. Figure 17 is a group of unnecessarily small drawings, of eight upper teeth, to show the relative heights of the tooth-crowns of Miocene and Pliocene "grazing (high-crowned) horses."

Although not so labeled, three of the teeth are lefts and five are rights. For consistent and useful orientation and comparison all the drawings should be of teeth from one side or the other. These drawings, reduced and rearranged from a paper by Stirton (who is properly credited in the list of text figures near the front of the book), represent teeth of differing stages of wear (from what Stirton called "practically unworn" to "moderately worn"), a fact which is unnoted in the label but which would have added interest and pertinence to the explanation of the figures. The caption does say, twice, that the drawings are of molars, whereas all but one are of premolars. This latter error does not significantly distort fact because the premolars which are illustrated are all quite molariform, but it does indicate haste or carelessness. It is repeated in figure 18 where the subjects of the drawings, three premolars, are called molars. This label further states that the drawings are "front views." One is, one isn't, and the third has been reversed from Stirton's drawing which showed the posterior or rear surface of the tooth. This also is, by itself, an unimportant mistake, but the label falsely suggests extreme precision.

The erroneous statement on page 117 that eohippus (slang for *Hyracotherium*) lacked the outer front toe (rather than the inner digit, the thumb or pollex) is contradicted and hence corrected by the comment on page 125 that the presence of the outer toe of the front foot made all Eocene horses four-toed. Prjewalski's horse is called a species (*Equus prjewalskii*) in the caption under Plate IV and is indicated as a race or a subspecies of *Equus caballus* on pages 6 and 17, on figure 3, and in the label on page XIII for Plate IV. In the discussion of "false horses," pages 158-60, the similarities of horse structures to the hypsodont teeth of the notohippid toxodonts and to the one-toed feet of the proterotherid litopterns are cited as examples of parallel evolution. Most authors would regard these similarities as convergence, as Simpson also does on page 213 in a discussion of parallelism and convergence, inasmuch as the ancestors of the groups involved were "distinctly different from each other." Other slips of this nature are rare in the book.

Specialists will probably carp about the way Simpson discusses such matters as the "principle of recapitulation" and how mutations occur, but the book will be a fine source of knowledge for its intended readers. They will find much that is familiar, will have plenty of opportunity to stretch their imagination and perception, and will enjoy with the author the wonderful story of horses. They will chuckle at the imagery and wonder if the choice of words is whimsical or inadvertent when he says that no skeleton of a certain rare kind of fossil horse has yet been mounted.

GLENN L. JEPSEN

Aspects of Form; edited by LANCELOT LAW WHYTE. Pp. ix, 249; photo. plates, line drawings. New York, 1951 (Pellegrini and Cudahy, $6.00).—Since Plato and Aristotle conceived of form as universal principle, and of the world as a hierarchy of forms, our knowledge as to the manifestations and basic laws of form has vastly increased. Although modern analytical science is directed causally and atomistically, both in theory and method, an understanding of reality cannot be gained without morphological considerations and concepts; in fact, there is a significant trend in our day of coming to grips scientifically with the various types of form expression. It was this situation that prompted the publication, under the title "Aspects of Form," of eleven articles dealing with inorganic, organic, psychological and aesthetic form, from physics to biology and art. Originally conceived as a catalogue to the exhibition on "Growth and Form" at the Institute of Contemporary Arts in London, this, in its kind probably the first, modern survey of form should be of interest to a wide circle of readers. Each article may be read by itself and provides specific information on phenomena and problems of form, shape, pattern and organization.

The subject is introduced by L. L. Whyte and the discussion opened by S. P. F. Humphrey-Owen, who elaborates the physical principles that underlie inorganic form, especially that of crystals. Visually perceived shape gives way to occupation of space as we pass from larger objects toward the atom, and, proceeding to the smallest physical entities, it becomes impossible to recognize or infer either form, shape, or the occupation of space. Shape and distance from the astronomer's point of view are treated by C. C. L. Gregory, in an account of the aspects of static and geometrical body shape, and of the "shapes-in-time" of systems in motion.

C. H. Waddington's brief essay on the character of biological form will speak to the heart of artistically inclined scientists, like this reviewer. Waddington compares with animal forms the shapes and structures of pebbles and driftstones of nature, describing how they influence archaic and contemporary man-made sculpture. F. G. Gregory deals with the complex and extensive subject of symmetry and form in plants, considering briefly principles of comparative morphology, the role of meristems, the effect of "external" and "internal" factors (terms not generally accepted), the alternation of sexual and asexual phases, and some phenomena of phyllotaxy. Joseph Needham, the biochemist, tells us that "neither the old-fashioned treatment of the systematic morphologist, nor yet the mathematisation of morphology in D'Arcy Thompson's great work, nor yet the traditional biochemical studies of purified substances or enzyme systems, are adequate for the present opportunities which we see before us in the unification of morphology and biochemistry.

The problem has to be approached on all levels simultaneously." Next A. M. Dalcq presents his views of embryonic development and animal form and function. Although concluding that some basic discovery is necessary before morphogenesis can be made fully intelligible, the Belgian embryologist expresses his belief in a non-mechanistic organicism, and in the principle of the primacy of order in morphogenesis, evolution, and mental achievements.

H. B. Cott describes the variety of patterns in animals which have arisen during the evolutionary process to conceal or emphasize their physical shape in the interest of protection. These adaptive modifications can be interpreted only in terms of the perception by other animals. The theme is carried further by K. S. Lorenz in his essay on the role of Gestalt perception in animal and human behavior. For the student of organisms it is important to distinguish between true "wholes" and sharply defined unchangeable structures, and similarly the student of behavior must recognize the complicated manner in which Gestalt perception interlocks and cooperates with other types of perceptory function that bear the character of mosaics. In the abstracting function of Gestalt perception, generic Gestalt or, as we might say, "ideal type" are highly significant. It appears that this kind of Gestalt perception is identical with the process that is generally called intuition, and Lorenz explains why intuition, as a typical "Wahrnehmung," is so easily deceived when left to itself. In an interesting article on activity patterns in the human brain, W. G. Walter describes how the patterns of the perceived world, which are extended in space, are related to the electrical rhythms in the brain. They can be demonstrated by an appropriate recording device, and the electroencephalograms thus obtained allow the establishment of three groups of individuals who differ from one another in their habits of thought and imagination, and consequently in matters of taste and personal compatibility.

The transition to interpretation of artistic form is made in the fine article by R. Arnheim. The aesthetic significance of a particular form depends on the interaction of psychological forces operating in the perceptual process of vision, in the area of motivation, on "personality," thinking, and memory. The author shows that the form of objects allows us to envisage the nature of life in its restless striving towards rest, and he explains why in works of contemporary artists beauty is so often lost, whenever form and meaning are split asunder. It is concluded that understanding of the relationship between visual form and the total organism can be obtained only if we take into account the complex interaction of the many forces that make up a person.

Well-known concepts used in traditional art interpretation, such as representational, abstract, conceptual, or primitive, often mislead us as to the meaning and motivation of a work of art that was created originally not just to imitate external forms, but in relation to functional and psychological needs. It is from this point of view that E. H. Gombrich meditates on the significance of various types of art forms and image-making, comparing them to the creation of a crudely conceived hobby horse which, to its maker, first of all serves as a functional substitute in place of some original or desired experience.

The text is supplemented by a number of good illustrations, and an interesting bibliography and chronological survey of Western ideas on form by the editor.

The most impressive feature of the book is without doubt the fact that form emerges as a general essential property of things: complex, highly differentiated, changing in space and time, and controlled by laws as yet little understood. The actual theme and the problem posed is the morphogenetic process, still obscure at many crucial points, or, more precisely, the *mechanics* of form. According to the editor's introductory statement, the aim was to treat the properties of form "only in so far as they are clearly set in space," and, consequently, "in the absence of a scientific philosophy of form," the *ideal* aspects in form experience are not stressed. As this reviewer is hoping to show elsewhere ("The Lesson of Form"—in course of publication), form permeates all levels of measured and experienced reality, and therefore it will be very important as a unifying motto in any program of general education designed to counteract those varied psychological and social factors causing within the individual the fragmentation or disintegration of an originally whole and harmonious experience. Whether we deal with an inanimate crystal, with the "morphaesthetic," regulative, dynamic organization of a plant, the psychological patterns of inner experiences, or the "Time-Gestalt" in the work of a Goethe or Proust, the unity of design is unmistakable. As even some of the articles in "Aspects of Form" show, it does not follow from the fact that certain properties of form are not set visibly in space and accessible to physical measurement, that they could not be subjected to an appropriate kind of scientific analysis: we may learn salient facts about form not only from a D'Arcy Thompson, but also from a Proust. Thus the content of this book becomes important for us also in a sense rather different from the intended one. This must have been felt by the contributors themselves, for whenever words such as form, order and orderliness are used, be the context physical, biological, psychological, or aesthetic, a bell rings in one's mind,

reminding that form is not only external shape and mechanical problem, but also non-material experience, symbol and idea. The spatial forms of nature are in the last analysis symbolic, and for man form can become a truly unifying principle and attain its crowning vindication only when consciously applied to the whole realm of human affairs, as a maxim supported by scientific knowledge.

ROBERT BLOCH

REVIEWS

A Monograph of the Echinoidea: Vol. V, part 2, *Spatangoida* (*cont.*) and *Index;* by TH. MORTENSEN. PP. 1-593; 286 text figs., 64 plates (quarto), and index of 63 pages. Copenhagen, 1951 (published, with the support of the Carlsberg Foundation, by C. A. Reitzel).—This brings to completion a truly magnificent monograph of the echini of the world, both recent and fossil. The several volumes, which have appeared at intervals since 1928, include a total of 4423 pages with 2468 text figures and 551 large plates. They embrace the fruits of some 30 years of intensive research by an outstanding scholar. The index covers the entire series of volumes.

Dr. Mortensen groups the echinoids in 10 orders, 17 suborders, and 56 families, and in this great monograph he has treated 703 genera and all the known species. His purpose has been not merely to describe the morphology of all known echini but to establish genetic and phylogenetic relations.

In this final volume (pp. 565-573) Dr. Mortensen summarizes three results of his phylogenetic study that have far-reaching importance and will be of special interest to paleontologists, most of whom have been raised on Jackson's *Phylogeny of the Echini.*

The first is the conclusion that *Bothriocidaris* is not an echinoid and, therefore, throws no light on the ancestry of this group. The Ordovician genera *Aulechinus and Ectinechinus* are accepted as the final and conclusive evidence that the lepidocentrids represent the primitive condition.

Dr. Mortensen further concludes that there is no justification for sharply separating the Paleozoic echinoids from later ones just because they have more than 20 columns of plates. He has therefore abandoned the order Perischoechinoidea of McCoy and made a three-fold split of the forms referred by Jackson to that order. The melonechinoids are made the subject of a new order, Melonechinoida; the archeocidarids are placed as a family in the order Cidaroida; and the remainder of Paleozoic forms are referred to a new order, Lepidocentroida. The latter, moreover, embraces not only the Paleozoic family Lepidocentridae but also the Mesozoic to Recent family Echinothuridae.

A third general conclusion is that compound ambulacral plates have evolved independently in several families of the regular echinoids so that a strong distinction between oligoporous and polyporous forms is a mistake.

Among the irregular echinoids which Jackson embraced in a single order Exocycloida, Dr. Mortensen recognizes four distinct orders. In the main this amounts to the elevation of groups regarded as suborders by Jackson to the rank of orders, but in one regard an important departure is made. The cassiduloids are removed far from the spatangoids and referred to the distinct order Cassiduloida of Duncan.

In view of Dr. Mortensen's convincing arguments and his firm conclusion that *Bothriocidaris* is not an echinoid, the reader will be confused to find that in this great work the class Echinoidea is divided (vol. 1, pp. 4-27) into two subclasses, Pseudoechinoidea (to include the order Bothriocidarida) and Echinoidea vera (to include all the true echinoids). This curious compromise with his convictions is repeated on pages 565 and 566 in the final volume.

No brief review can do justice to a work so vast in scope and so exhaustive in detail. The text has been prepared with meticulous care, the text figures are all original and effective, and the plates in full-tone reproduction leave nothing to be desired. Dr. Mortensen's Monograph of the Echinoidea will excite the admiration of neontologists and paleontologists alike and surely it will endure through the centuries as one of the great monuments in taxonomic literature.

CARL O. DUNBAR

Les Stromatoporoïdes du Dévonien Moyen et Supérieur du Bassin de Dinant, Première Partie; by MARIUS LECOMPTE. Inst. Royal des Sci. Nat. de Belgique, Mem. 116. Pp. 215; 35 plates. Brussels, 1951.—This handsome and impressive volume is based upon extensive collections of uncommonly well preserved stromatoporoids from the Middle and Upper Devonian rocks of southern Belgium. Among them Dr. Lecompte recognizes 13 genera, 106 species, and 17 subspecies. It is noteworthy that in a region so long studied, more than half of the stromatoporoids (73 species and 14 subspecies) are new.

In the introduction (65 pages) the morphology of the stromatoporoids is discussed and it is concluded that the astrorhizae constitute the most distinctive feature of the group, that they were in some fundamental manner connected with the formation of the skeleton, and that they are invariably present; but Dr. Lecompte is forced to conclude that their function is still an open question.

Conflicting views on the systematic position of the stromatoporoids are ably reviewed, following which six lines of evidence are

marshalled to show that they are allied with the hydroids and not with sponges or foraminifera.

The quarto plates in full tone reproduction showing internal structure in thin section are magnificent.

CARL O. DUNBAR

On the Fish-like Tail in Ichthyostegid Stegocephalians; by ERIK JARVIK. Meddelelser øm Grønland, Band 114, No. 12. Pp. 1-90, 36 text figs., 21 plates. Copenhagen, 1952.—Discovery of the oldest land vertebrates in 1931 is one of the outstanding achievements of the Danish expeditions to East Greenland under the leadership of Lauge Koch. But when these were first described (Säve-Söderbergh) in 1932, the new order Ichthyostegalia, the family Ichthyostegidae, and its two genera, *Ichthyostega* and *Ichthyostegopsis*, rested almost entirely on skull characters, the rest of the skeleton being unknown. In subsequent years, therefore, Dr. Koch repeatedly sent parties to collect from the late Devonian beds on Gauss Peninsula until the collections now include about 170 specimens (of which over 100 are skulls or parts of skulls) of ichythyostegids in addition to many fine specimens of the associated (and closely related) crossopterygian fishes. In 1948 the search was rewarded by the finding of two remarkable specimens, one consisting of a well preserved tail (of a type previously supposed to be a crossopterygian fish) with an articulated pentadactyl hind foot, the other of a skull with most of the skeleton including the shoulder girdle and the humerus. It is this material to which Dr. Jarvik's monograph is devoted.

In order to show its significance he describes a new ichthyostegid genus, *Acanthostega*, and a new crossopterygian genus, *Eusthenodon*, the latter being closely similar to the American genus *Eusthenopteron*.

Unlike all later tetrapods, the tail in these Devonian stegocephalians is structurally very similar to that of the contemporary crossopterygian fishes, even to the extent of bearing vestigial scales. The vertebral column likewise closely resembles that of the fishes, but the limbs, though short, were distinctly pentadactyl. Here indeed is a veritable connecting link between two great groups of the animal kingdom, the crossopterygian fishes and the tetrapods. For this remarkable discovery we salute both Dr. Koch and Dr. Jarvik.

CARL O. DUNBAR

Paleontology and Modern Biology; by D. M. S. WATSON. Pp. xii, 216; 77 figs. New Haven,, 1951 (Yale University Press, $4.00). —For over forty years D. M. S. Watson, now Emeritus Professor of Zoology, University College, London, has been making important

contributions to our understanding of the origin and evolution of the various groups of premammalian vertebrates. In 1937 he summarized certain aspects of his work, as well as his views on vertebrate evolution, in the Silliman Memorial Lectures which were given at Yale University. Because of war-time duties in Great Britain, he was unable to prepare the lectures for publication until recently. The resulting volume also contains a series of appendices that discuss the later advances in the various topics under consideration.

Professor Watson has selected a series of paleontological "problems," all of which have been investigated by himself, to demonstrate "the validity of the methods of reasoning" employed in the study of structural change in a successive series of fossil vertebrates. He supports the conclusion that the methods of morphology are valid because they permit verifiable predictions. Three cases are described in which a hypothetical morphological condition has been verified by paleontological data. Perhaps the most striking and least controversial is the demonstration of the reptilian homologies of the mammalian auditory ossicles in the mammal-like reptiles, as predicted by Reichert on embryological evidence. Within reasonable limits few morphologists or paleontologists will question this thesis, and additional examples might be cited in its support. The validity of the prediction obviously depends on the nature of the supporting evidence, and on the evaluation of this evidence.

Evolutionary trends in various groups of labyrinthodont amphibians are described in some detail. They illustrate the use of the morphological method in evaluating structural change in a series of geologically successive genera that are not necessarily closely related but that demonstrate the nature of suprageneric trends within perhaps suborders or superfamilies. This method is of wide application, and it offers a means of obtaining data for evolutionary rates in groups of animals that cannot be resolved into true phyletic lineages. Certain distinct lines of labyrinthodonts show strikingly similar modifications during essentially the same time interval. To regard these parallel trends as essentially nonadaptive (p. 194 and elsewhere) is perhaps begging the issue, even though their adaptive significance cannot be surely determined. Likewise the trend toward a reduction in ossification in the amphibian skull and in certain groups of fishes may have a real adaptive value, rather than being the result of unknown "internal factors" (pp. 197-198).

The problem of tetrapod origin is discussed to illustrate how the previously described post-Carboniferous labyrinthodont trends, "by projecting them backward," may be utilized to predict the structure of the Carboniferous ancestors. The hypothetical condi-

tions thus determined are largely realized in a number of primitive Carboniferous forms. Working in the other direction, larval labyrinthodonts with gill slits and external gills, and a late Permian neotenous form, offer additional evidence regarding the ultimate ancestry of the perennibranchiate Amphibia.

Following a consideration of the amphibian affinities of *Seymouria*, the origin and early history of the reptiles is reviewed, particularly in relation to the seymouriamorph discoveries in Russia and the recent work of Olson, Romer, and Westoll. Professor Watson supports the view that the captorhinomorph reptiles were in the line leading to the mammals, while the diadectomorphs gave rise to the other groups of reptiles. The illuminating description of the changes leading to the mammalian middle ear is one of the most interesting chapters in the book. Watson and Westoll have concluded independently that the mammalian tympanic membrane is not homologous to the one in reptiles, the former being derived from the outer wall of an anterior diverticulum of the tympanic cavity presumably present in the cynodonts. The elucidation of the history of the mammalian middle ear is certainly one of the great triumphs of morphological reasoning, and these new deductions are important additions to a nearly unique story of structural and functional transformation.

Throughout the book, Professor Watson has attempted to explain morphological change on a functional basis. This welcome departure from straight description is further developed in his consideration of adaptative change in the long- and short-necked plesiosaurs. An interesting comparison is made between the swimming efficiency of the plesiosaurs and ichthyosaurs.

The last chapter is concerned with evolutionary mechanisms. While evolutionary biologists will agree with many of Professor Watson's conclusions, there are others that will be questioned. One is the occurrence of nonadaptive "direct evolution" within various labyrinthodont lines; fundamental changes are regarded as nonadaptive, although "many consequential rearrangements" are considered adaptive. Another is that the changes considered in the preceding chapters "cut across specific differences" and "the origin of species is a phenomenon which has little to do with the main course of evolution."

Professor Watson has brought together in this volume the results of many years of careful and fruitful investigation. It is unfortunate that the information in the appendices could not be incorporated into the main text, particularly since new facts have altered the interpretation of several major and some minor topics considered in the original lectures. The title of the book is perhaps too inclusive for its contents. These are, however, not serious

criticisms. The book is packed with a wealth of interesting morphological and functional detail that will be very useful to students of vertebrate evolution. The many thought-provoking discussions on the meaning of structural change will interest those concerned with problems of evolutionary modes and mechanics.

BOBB SCHAEFFER

Dana's System of Mineralogy, 7th ed., Vol. II; by CHARLES PALACHE, the late HARRY BERMAN, and CLIFFORD FRONDEL. Pp. xi, 1124. New York, 1951 (John Wiley & Sons, Inc., $15.00).—The first volume of this edition was reviewed in this Journal, vol. 243, pp. 219-224 (1945). The second volume covers Halides, Carbonates, Nitrates, Iodates, Borates, Sulfates, Selenates and Tellurates —Selenites and Tellurites, Chromates, Phosphates, Arsenates, and Vanadates, Antimonates, Antimonites and Arsenites, Vanadium Oxysalts, Molybdates and Tungstates, and Organic Compounds.

The methods of presentation and classification follow closely those used for Volume I and need not be reviewed here. As they did in the first volume, the authors have done a notably successful job of thorough compilation, discriminating selection of data, and skillful interpretation of broad relationships. Volume II is noteworthy for its content of a very large amount of hitherto unpublished data on many minerals. This includes determinations of unit cells (for more than 30 minerals), specific gravity, hardness, optical data, fluorescence, twinning, and other properties.

A regrettable omission is that of graphical presentation of optical data for binary and ternary series. These are available elsewhere, but would have enhanced the usefulness of the volume. The typography is like that of Volume I, with the same fault of poor headings for the mineral species. Otherwise the printing is excellent and there are few misprints.

Every mineralogist will want this volume and all eagerly await the third and final volume containing Silicates.

MICHAEL FLEISCHER

The Interpretation of X-ray Diffraction Photographs; by N. F. M. HENRY, H. LIPSON, and W. A. WOOSTER. Pp. x, 258; illustrated. Copyright 1951 by Macmillan and Co., London (42s). United States agents, D. Van Nostrand Co. ($8.50).—The subjects of the 17 chapters in this excellent book include the following topics: crystal symmetry and geometry; X-rays and the geometry of X-ray reflections; rotation, oscillation, Laue, Weissenberg and powder photographs; fibre photographs; orientation studies; measurement of grain size; measurement and calculation of intensities; accurate measurement of cell dimensions; identification of unknown materials. Appendices, tables, and indices occupy 21 pages. Exercises at the

ends of some of the chapters provide additional examples but should be supplemented by laboratory work.

The book is ideally suited for a thorough first course in X-ray crystallography. The practical approach will appeal to persons who do not care for the more mathematical treatment given in many texts; at the same time, sufficient theory is presented to afford a sound basis for further work or for independent research. This book leads the student up to, but does not include, the actual solution of crystal structures. Its culminating chapters describe many valuable applications of X-ray diffraction in modern technology.

It is regrettable that trans-Atlantic shipping and marketing costs should increase the price more than 44% on a useful scientific book of this type. HORACE WINCHELL

Plane Table Mapping; by JULIAN W. LOW. Pp. xvii, 865; 148 figs., 8 tables. New York, 1952 (Harper and Brothers, $4.50).—It has long been this reviewer's contention that a geologist, through an understanding of geomorphology, is better equipped to make a topographic map than is a civil engineer or surveyor. This contention, of course, is based on the assumption that the geologist has a fundamental knowledge of mathematics and surveying principles. Apparently, and unfortunately, this assumption is not often fulfilled. "Plane Table Mapping" is, in part, evidence that the assumption is often a fallacy, since the manual was first prepared for The California Company for their new "scientific trainees" who "were, with few exceptions, inadequately trained in and lacked experience in the common field procedures." Many others have noticed this same lack of training.

This manual should do much to improve the situation since it is admirably suited to fulfil the role of a reference text in plane table surveying courses. Instructors can easily adapt the manual to their course, or vice versa, with the result that students should be better trained in this surveying technique. The text enables the instructor to emphasize what he considers to be the more important sections and to add information which he feels is not adequately covered in the manual. For instance, a listing of different county, state, and federal offices which have various base maps available would be of value to tyro geologists.

Low's manual, however, will probably be even more appreciated by field geologists and engineers, since the text provides a portable and ready reference for the specialized technique of plane table mapping. The format of the text is ideal for this need since it has almost the same dimensions as the Post field notebook and it is further provided with a flexible cover of good quality.

The scope of the manual is ample. Besides a thorough treatment of basic fundamentals of plane table surveying and further information on both the modification of the procedure according to the scale of the map and the factors which must be considered in determining the scale of mapping, the text includes information on the adjustment, care, and repair of instruments, the application of aerial photographs to plane table mapping, and condensed remarks on drawing instruments and hints on different techniques and methods used in drafting maps. The appendix, containing the mathematical tables, is short, concise, and sufficient.

With the publication of "Plane Table Mapping," Mr. Low has earned the appreciation and gratitude of engineers and geologists whether they be students, instructors, or field men.

MEAD LEROY JENSEN

Ecological Animal Geography, 2d ed.; by W. C. Allee and Karl P. Schmidt. Pp. xiii, 715; 142 figs. New York, 1951 (John Wiley and Sons, Inc., $9.50).—This, the second edition of the 1937 text derived from Hesse's pioneering "Tiergeographie auf oekologischer Grundlage" of 1924, is a valuable textbook in the field of modern ecology. The original material of the earlier works has been considerably modified, and the bibliographies at the ends of chapters have been expanded and brought up to date. A tremendous amount of material has been condensed and grouped into these pages under the main headings of: 1) Ecological Foundations of Zoögeography, 2) Distribution of Marine Animals, 3) Distribution of Animals in Inland Waters, A Phase of Limnology, and 4) Distribution of Land Animals. Under these headings there are twenty-eight chapters on various aspects of the general problem. In general the material is covered admirably, although the very mass of it sometimes makes digging out particular items rather difficult. It seems to me, perhaps uncritically, that the discussions of the marine forms of animals are more comprehensive than are those of the terrestrial forms, of invertebrates, fish and amphibians and reptiles, better than mammals and birds. But perhaps the literature on ecological geography in the former groups is merely larger and more comprehensive than in the latter. Under the section on "Rules" such as Bergmann's Rule, I missed an interesting phenomenon discussed by Murphy and others on the larger size of bills of birds from islands. Some of the cuts need freshening up, particularly the map cut (fig. 116), and I have always felt that the cut of the two antelopes (fig. 115) from Brehm's "Tierleben" as an evidence of Bergmann's Rule was, if anything, rather silly, as the two genera are not closely related. But then cuts or illustrations in biology texts are often one of the great difficulties.

The discussion at the end of the book about the urgent necessity for world-wide conservation of natural resources is a valuable addition in this edition, although unfortunately the readers of this text will undoubtedly be already aware of the need for conservation and in favor of it. However, it is a subject which all teachers of biology should stress at the risk of boring their hearers with repetition.

Altogether this new edition of an invaluable work takes a long stride towards keeping up with the increasing mass of evidence being accumulated around the world about the biogeography of our planet, and it is a valuable addition to any basic library of biology.

S. DILLON RIPLEY

PUBLICATIONS RECENTLY RECEIVED

The Origin, Variation, Immunity and Breeding of Cultivated Plants; by I. N. Vavilov, translated by K. Starr Chester. Waltham, Mass., and New York, 1949-50 (The Chronica Botanica Co., Stechert-Hafner, Inc., $7.50).

Philosophical Problems of Mathematics; by Bruno Baron v. Freytag gen. Loringhoff. New York, 1951 (Philosophical Library, $2.75).

Logic for Living, Lectures of 1921-22; by Henry H. Williams. Edited by Jane R. Hammer. New York, 1951 (Philosophical Library, $3.75).

Correlation of Domestic Stoker Combustion with Laboratory Tests and Types of Fuels: IV, Combustion Tests of Illionois and Other Coals; by Roy J. Helfinstine. Illinois State Geological Survey Report of Investigations 151. Urbana, 1951.

Manhood of Industrial Engineering; by K. Theodore Korn. Cleveland, Ohio, 1951 (Edward A. Berk & Associates).

Ultraviolet Spectra of Aromatic Compounds; by Robert A. Friedel and Milton Orchin, New York and London, 1951 (John Wiley & Sons, Inc., and Chapman & Hall, Ltd., $10.00).

Trace Elements in Plant Physiology; A Symposium organized by the International Union of Biological Sciences at the Rothamsted Experimental Station with a Report of the Proceedings by T. Wallace and a Foreward by M. J. Sirks. Waltham, Mass., and New York, 1950 (The Chronica Botanica Co., Stechert-Hafner, Inc., $4.50).

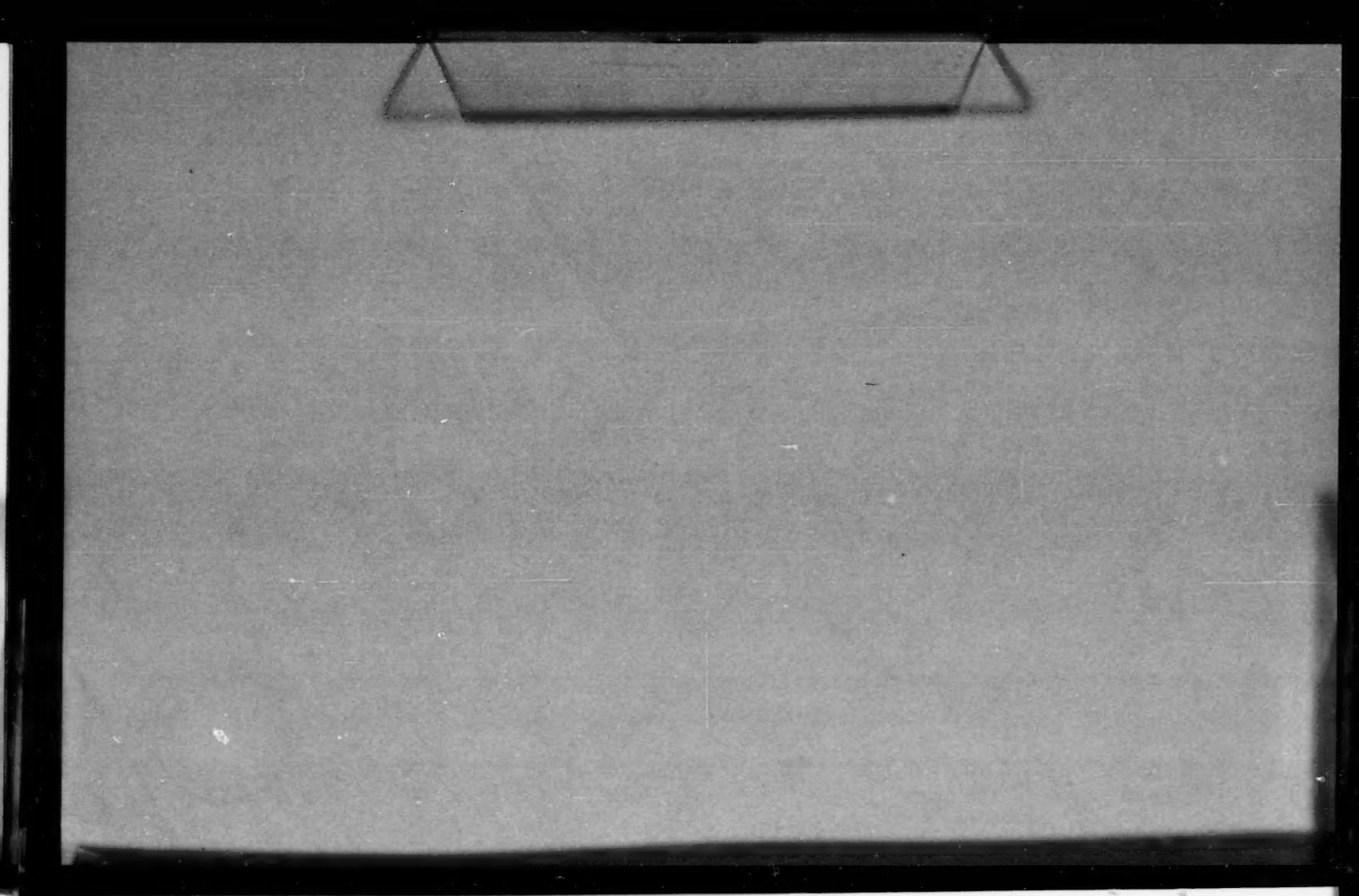
Modern Magnetism, 3d ed., revised; by L. F. Bates. London and New York, 1951 (Cambridge University Press, 5.50).

Fundamentals of Automatic Control; by G. H. Farrington, New York, 1951 (John Wiley & Sons, Inc., $5.00).

La Structure des Theories Physiques; by Paulette Destouches-Fevrier. Paris, 1951 (Presses Universitaires de France).

Internal Constitution of the Earth, 2d ed., revised; by Beno Gutenberg. New York, 1951 (Dover Publications, Inc., $6.00).

Dana's System of Mineralogy, Volume 2, 7th edition; by Charles Palache, (the late) Harry Berman, and Clifford Frondel. New York and London, 1951 (John Wiley & Sons, Inc., and Chapman & Hall, Ltd., $15.00).



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